WHY AND HOW

A BOOK OF EVERYDAY SCIENCE

DESCRIPTIVE AND EXPERIMENTAL

BY

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AND

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(WITH 123 ILLUSTRATIONS)

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PREFACE

OUR aim is to interest and inspire boys and girls of all ages—especially those from twelve to sixteen years Our text is, "Why? How?' Young people are constantly asking, "Why does ?' "How does it . . . ?" A large number of such questions have been collected, and, after classification, used as the groundwork of this book

It is not to be desired that the flow of inquiry should be staunched, it is rather to be hoped that the knowledge gained may promote further seeking after enlightenment

The chapters are arranged in a logical sequence, and illustrations of scientific laws are chosen from common processes—processes which often are not considered noteworthy simply by virtue of their familiarity and nearness to us—as, for instance, the unlocking of a door, the lifting of a bucket, the turning of a screw-driver.

In order to encourage private research and individual effort on the part of the student, further simple practical applications of the principles treated have been appended The further experiments suggested will be found to form a valuable recapitulation of the subject-matter

These experiments, as well as those described in the text, may be performed by the use of such

apparatus and materials as an ordinary household would furnish, thus obviating the necessity for the usual laboratory equipment.

The book, in addition to its general usefulness, will provide Evening School students of Preliminary General Science (including Mechanics, Hydrostatics, and Heat) with an attractive and easy treatment of their subject

The illustrations are numerous, and the experiments have been successfully performed many times by the authors and have received due appreciation

E. S.
A R.

1. Introduction.

There are wonders all around us—far away and near at hand—in the air, on the earth, and in the sea There are wonders natural and wonders artificial Some of the natural wonders are at once evident to our senses, but others have been discovered only after much study and great perseverance, the artificial wonders are due to man's power of mind and of body

The wonders of nature are far, far beyond man s achievements, and we can account for them only by the existence of mightier forces than man has yet been able to employ, forces perhaps more subtle than he can ever hope to understand Since man appeared on the earth his powers have gradually developed and because he has the ability to reason he has himself produced many wonders With many of these wonders we have become so familiar that we have ceased to be surprised by them

People often speak of our time as the age of wonders, but the truth is that every age has been an age of wonders, because there have always been men who realised that the world is full of forces which might be mastered, or at any rate harnessed, to do very useful work, and in the investigation of these forces men have been led to wonderful discoveries

"Think nought a trifle, though it small appear,
Small sands, the mountains moments make the year,
And trifles, life'

2. Why Reins Are Made Of Leather.

It is not difficult to prove that there is air at every point on the earth's surface We can feel its presence when we wave our hands quickly We can feel it, too, when we are struggling against a strong breeze or when riding on the top of a tram-car When walking through the air in our rooms at home we do not notice that it offers any resistance to our movements A balloon rises and passes through the air quite easily, and the wing of an aeroplane cuts through it without the slightest difficulty

It is not so easy to make our way through water The swimmer knows that he cannot swim as quickly as he can walk The fastest railway engine travels at a much greater rate than the fastest ship The swimmer and the submarine have to overcome some resistance on the part of the water Yet, the resistance offered is not too great, for men swim easily under water and fishes move and turn about quite comfortably We may say then that air offers little or no resistance, but that water does offer some resistance

Now, think what would happen if we were locked in a room We should have no difficulty in walking through the air to the door, the wall, or the window, but having arrived there we should be compelled to stop, and if our lives were in danger we should consider breaking the window or hammering down the

door Certainly we could not walk through the solid wall or through the door, because the wall and the door would offer too stout a resistance to our bodies It is only in fairy tales that rocks divide and mountains move at the sound of a magic horn

Why should most solids be so difficult to penetrate whilst liquids and gases can easily be penetrated? Can it be that the matter composing solids is bound together by a greater force than the matter composing liquids or gases?

Let us consider the following experiment Take three glass vessels, and in the first one place a lump of iron We find that the iron keeps its own shape In the second one place a quantity of water We see that the water quickly accommodates itself to the shape of the occupied part of the vessel, and we can distinguish its surface quite clearly Now fill the third one with coal gas by holding it over an unlighted gas jet We cannot see the gas, but we know that, unless confined by some kind of lid, it will spread itself out of the vessel and into the room All substances are composed of molecules—a molecule being the smallest particle of a substance which can exist and yet retain all the characteristics of that substance Remembering this fact, we are led by these and similar experiments to certain definite conclusions

1 A very great force binds the particles of the iron to one another so strongly that they cannot easily escape from its surface They thus remain bound together and the lump retains its shape

2 When water is poured into a vessel its particles move about freely, and the water flows until finally it occupies its maximum space in the vessel and has its surface level Is there a force controlling the movement of the water particles? Yes, and it keeps them together at the surface of the liquid

3 The particles of a gas flow and spread more readily than those of a liquid As it has no surface of its own we conclude that there can be no binding force in a gas

This binding force or attraction between particles is known as **cohesion**, and it is one of nature's greatest forces A simple experiment will show how great it can be even in a liquid From *stout* cardboard cut a spoon shaped pattern of a circle and rectangle joined together (*Picture* 1) Bend the card so that the circle rests just on the surface of the water in a glass tumbler, and arrange that the greater part of the rectangle projects horizontally over the rim The cardboard circle is, of course, wetted by the water in the vessel, so that to pull away the circle from the liquid the force of cohesion between the water molecules will have to be overcome Try to do this by placing pennies on the end of the projecting rectangle We are surprised to note the weight of copper necessary to separate the wet card from the water

Picture 1

Cohesion in solids is often very difficult to overcome, and our strongest efforts to get the better of it are sometimes powerless. The cohesion of the stones in the walls of cities, such as Chester, has often protected the citizens against the furious attacks of a besieging army. Armour-plate and the walls of our strongest safes can be made to resist the heaviest onslaught, and this is solely due to the strength of the force of cohesion in them

The varying degrees of hardness with which we are familiar in the different bodies around us show clearly that cohesion is greater in some substances than in others We find that cohesion is very strong in a diamond—so strong indeed that no metal instrument can cut it, and if we wish "to dress" a diamond we are compelled to rub it against another diamond Because of their hardness diamonds are used by glaziers to cut glass and by oil-prospectors to bore rocks Metals exhibit a weaker degree of cohesion than diamonds, as is shown by the fact that filings of iron, copper, brass, and other metals can be detached from a solid lump by means of a hand-file The force of cohesion is weaker again in stones, which often break or are crushed to powder under the blows of a hammer.

It is by the overcoming of the cohesion between their molecules that grindstones and whetstones are worn, that roads become dusty, and that sea-shore rocks are reduced to sand Why must a sculptor use a chisel and a heavy mallet to carve stone, whilst

The barrels of large artillery guns for land batteries and warships are *wire wound* to enable them to withstand the shock caused by the shell passing through In a lesser degree, a similar object is attained by binding wooden casks with bands of iron

All metals are not equally tenacious—for example, copper is not so strong as iron Because the cohesion of copper is rather low many attempts to lay the transatlantic cable failed—the copper, of which the cable was composed, was unable to stand the strain imposed upon it It was not until Charles Bright succeeded in increasing the tenacity of the cable by wrapping steel wire round the copper that the difficulty was overcome.

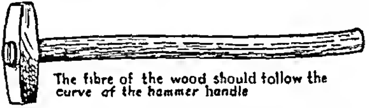
The tenacity of metals is generally high, but other substances are equally strong It is surprising to note how great is the tenacity of cotton A single fibre of raw cotton is able to support a weight four million times as great as its own weight Were it not for the effect of damp and frost on its fibres a cotton rope would be one of the strongest materials known

Hemp and jute fibres are very tenacious, and it is found possible to make very strong ropes and rope-ladders from these substances Because of its tenacity a hempen rope does not break when used for a tug-of-war This explains also why a string hammock can bear the weight of a heavy person, and why it is not easy to break linen thread

Tenacity in a block of wood is due to the tensile strength of the hundreds of fibres of which it is

composed Each fibre behaves like a strong wire, and that is why a block of wood shows greater tenacity *along* the grain than *across* it The joiner always considers this difference of tenacity whenever he constructs a timber support for a heavy object.

Examine the shaft of a heavy hammer In which direction does the grain run through the wood



Picture 3

(*Picture* 3)? It runs from end to end in order to make the tenacity of the shaft as great as possible, and so enable it to withstand the strain when the hammer is in use

A great part is played by tenacity in the lives of animals and insects The spider spins a very fine web, so fine, indeed, that it is almost invisible, and yet so strong, because of cohesion, that it will support the weight of a comparatively heavy wasp without breaking Some tropical spiders can spin a thread strong enough to bear the weight of a small bird When once a spider has caught a fly it makes its victim secure by binding its wings with a thread, the tenacity of which is so great that the most desperate efforts of the fly cannot overcome it.

Hunters in Africa describe in their jo

difficulty they have experienced in shooting such game as the elephant and rhinoceros because of the very stout hides of these animals Nature has provided them with an armour plate which has such tenacity that heavy ammunition must be used if we wish to pierce it When David Livingstone was exploring the heart of Africa he frequently encountered savage tribes who went to war armed only with spears and huge shields made of raw hide stretched over wooden frames The hide was very tenacious, and gave ample protection to the warriors During the Great War it was reported that the stout leather jerkin worn by many soldiers, although not impenetrable, helped to preserve lives

When hide has been tanned its tenacity is increased, and this makes it possible to use leather for a variety of purposes Frequently boots and shoes are fastened with laces made from leather, and, in our factories, driving belts are usually joined at the ends by leather lacing which wears as long as the belt On the cattle ranches of Canada the cowboys use lassoes of light leather, which can be subjected to the strain of a struggling steer without breaking Harness makers find the tenacity of leather a great help to them, and the reins and traces made from it do not give way to the pull of a very strong horse (For exceptionally heavy work chains are sometimes used as traces)

Leather has other properties besides tenacity which make it the most suitable material for reins It is flexible, and this enables the driver to govern his

horse easily and to drive with a "slack rein" whenever he wishes Leather is comfortable to touch and it is only very slightly porous We shall consider these properties in later chapters Moreover it is comparatively cheap, no cheaper material possesses its strength, its flexibility, and its comfortable touch

The silkworm is an insect which spins a thread which is stronger than any vegetable fibre Silk, as it comes from the cocoon, is more cohesive than a thread of steel of the same thickness, and thus the silkworm is safely protected during its period of changing into a moth Even though the twisting of silk fibres into a skein decreases their tenacity, silk thread is nevertheless very strong, and a dressmaker finds it very difficult to break embroidery silk with her fingers

We are now able to understand why a solid generally retains its shape, why a liquid takes the shape of the vessel containing it, and why a gas has neither definite shape nor size Further thought will enable us to explain why a gas can be compressed easily, and why it is difficult to compress liquids and solids We have also learned that there is a giant force called cohesion, which holds together the molecules of solid and liquid substances Without this force everything would be shapeless and gaseous, and once again the earth would be "without form" There could be no raindrops no sheets of metal, no tenacious wires, no hard substances of any kind whatsoever

Further Experiments.

1 Take three tall jars of equal depth and fill the first with sand, the second with water, and leave the third containing only air Rest a flat ruler across the top of the jars and place three pennies on the ruler, one over each jar Remove the ruler quickly Which penny reaches the bottom of the jar first? Explain what occurs

2 Try to write on paper with the head of a match Now strike the match but extinguish it before the wood has burned away Again try to write How do you account for the difference?

3 Stretch a sheet of tissue paper, a sheet of writing paper, and a sheet of drawing paper over separate frames Shoot pellets at them, using a catapult Which is the most tenacious sheet?

4 Place three matches together and try to break them between the finger and thumb Take three more matches and wrap them tightly with thin wire in close coils Now try to break the matches as before Explain the effect of the wire

5 With a sharp knife split a wooden rod down the grain Now cut the rod across the grain Repeat the experiment, using a roll of clay instead of the rod What inferences do you draw?

6 Tie a boy's hands together, using one strand of sewing cotton Can he break the thread? Now twist ten strands together and with this tie his hands again. Can he break this? Why?

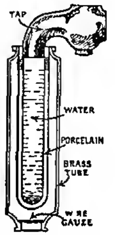
3. How a Fountain-Pen Works.

Place a lump of sugar in a tumbler and fill the vessel with water What happens? Our sense of taste tells us that the water on the surface becomes sweetened This means that some of the sugar has passed through the water, from the bottom of the vessel to the top We notice a similar process if we use a few drops of ink in place of the sugar We see that the ink rises and diffuses through the water till it has coloured the whole liquid

Let us experiment again Pour a thimbleful of water into a small vessel and add to it another thimbleful of methylated spirit Now, measure the volume of the mixture It occupies rather less space than two thimblefuls Where has the vanished liquid gone? Scientists explain the loss in volume by saying that a portion of the spirit has filled the spaces between the water particles These spaces are known as pores, and are so called from the name of the openings we can see in our skin when we examine it through a magnifying glass

Many substances are so porous that the pores may be seen with the naked eye, as, for example, in chalk, pumice, and sponge In other substances the pores are discovered with some difficulty Lead and iron are of this class, but Francis Bacon in 1640 proved the porosity of lead This he accomplished by compressing a hollow sphere of lead filled with water

find that after using it for a few days it has extracted a fine muddy deposit from the water



Picture 5

Cloths of various kinds have been used for filtering liquids For example, outpost riders among the hills of India often find no water available except the muddy water from streams Before they can use this water for drinking purposes it must be filtered To do this, they pour the muddy water into a hat and collect the liquid which percolates through the fabric A similar method is used by housewives for extracting the juices of fruits The crushed fruit is hung in a jelly bag—*i e*, a canvas bag shaped like a clown's hat inverted (*Picture 6*)—and the liquid juices are filtered from the solid pulp For very delicate filtrations a chemist uses a filter paper, which is simply a thin layer of blotting paper of very fine texture He lines a funnel with this, and pours into it the mixture he wishes to separate

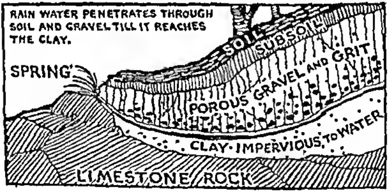

Picture 6.

Porous substances readily secrete gases as well as liquids in their pores It is therefore advisable, in order to absorb the obnoxious fluids, to place a piece of charcoal in a meat safe, in the air pipe of a lavatory basin, and in the water in

which a bulb is growing The charcoal must be frequently renewed for its pores are soon filled, and then no further absorption can take place

The sugar which we see in the sugar basin has the appearance of white crystals, but the syrup from which it is manufactured is dark brown This change is caused by passing the syrup over animal charcoal, which has very fine pores that take up the colouring matter

Respirators were used during the Great War to protect the soldiers from the effects of poison gas They were charged with such substances as charcoal and tow, so that the air was filtered from the poisonous gases in passing through the respirator



Picture 7

Much of the rain which falls on the earth s surface does not drain away in streams and rivers, but sinks through pores in the soil and nourishes the roots of the grasses, plants, and trees, which are very dependent

on the porosity of the earth for their growth. Water often continues to soak through the soil till it comes to some stratum, like clay or granite, through which it cannot pass (*Picture 7*). In this case it sometimes forms an underground lake, or it may follow the impervious stratum to the earth's surface again, and so form a spring.

Vessels for holding liquids should be very nearly impervious. A great advance was made in the pottery trade when Bernard Palissy discovered a method of glazing the surface of pottery so that it would hold liquids without any leakage due to porosity. In making the discovery Palissy nearly ruined himself and his family. His efforts to make his furnace hot enough to produce a glaze were only rewarded after he had broken up the furniture of his home to provide fuel for his fire. This final effort turned out successfully, and since that time delicately glazed china vessels have taken the place of the thick and heavy porous earthenware previously in use. The sizing of paper closes the pores, and acts in exactly the same way as glazing does in the making of pottery. Thus, writing with ink on paper has become possible, for without an impervious surface the ink would soak through and spread over the paper as it does when we write on blotting-paper.

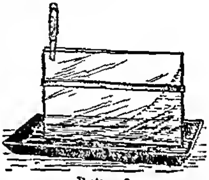
It often happens that a fabric has to be waterproof, and to make it so its pores are closed by a thin layer of rubber, or other non-porous substance. One impervious substance widely used for this purpose is

tar, which is spread over the surface of canvas to make tarpaulin cart sheets It is also spread over thin layers of felt to make a cheap roofing material Pitch is frequently used instead of ordinary tar, as it is equally impervious The sides of a boat are often coated with one of these substances in order to make the wood work impenetrable by sea water—hence the proverb, "Don t spoil the ship for a ha'p'orth of tar" The gable end of a house is made damp proof by a slate covering or by tar painting A damp proof course of tarred felt, slate, or glazed brick is generally placed just above the foundations of buildings to prevent the moisture passing upwards through the bricks

Leather is an almost impervious substance The skin bottles which were used in Palestine, and the leather cups from which the Saxons drank their mead, did not lose much liquid by porosity But leather is not absolutely impervious, as we find when we examine our boots after a day's tramp through the snow or rain To make leather damp-proof we may coat it with a layer of oil blacking, and thus, perhaps close the fine pores

If we examine under a microscope those substances which soak up liquids we are able to see thousands of hair like pores through which the liquid is drawn These are known as capillary tubes (Latin, *capillus*, a hair) The smaller the bore of these tubes is the higher the liquid will rise in them We can illustrate this principle thus Bind together with a strong

elastic band two clean glass photographic negatives from which the films have been stripped (*Picture* 8) By slipping a knife between them at one edge they can be separated slightly so as to form a V shaped enclosure of air Now hold the plates with the touching edges at right angles to the water surface Then

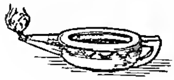


Picture 8

dip them for about one third of an inch into a tank of coloured water The water rises between the plates and forms a concave surface The height of this curve increases as the plates get closer to each other The same effect may be produced by using any liquid which wets the plates If mercury (a liquid which does not wet the glass) is used we find that the curve is convex and is depressed below the mercury surface in the tank

Capillarity, as this rising of liquids up a tube is called, is the method by which blotting paper and cloths soak up the liquids with which they come in contact The lamp wick and the lubricating oil dripper are further examples of the same principle In the days before metal burners were used in lamps, lights were obtained by the burning of oil The oil was contained in a long, shallow vessel (*Picture* 9), and one end of a rush was dipped into it By ' '

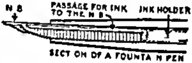
means the oil was soaked up to the other end of the rush, where it could be burned Candles and tapers



I cture 9

keep themselves alight by the burning of wax in the form of vapour the liquid rising by capillarity up the cotton wick Because of capillarity a piece of cotton may be arranged to siphon water from one vessel to another

The fountain pen depends on capillarity for its feeding system From the ink reservoir a narrow vulcanite holder runs to the nib (*Picture* 10) and in this vulcanite a very fine groove is cut The capillary flow of the ink from the



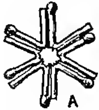
I cture 10

barrel along this groove gives the nib a sufficient supply of ink for writing purposes

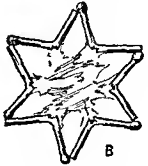
When an elastic capillary tube is filled with liquid it is often much larger than when empty and this explains why a wooden door often swells in damp weather but warps on hot days It is because the fibres of a rope easily take up water by capillarity and swell that a scout slackens his tent lines before a storm breaks.

A novel way of showing the swelling due to capillarity is to bend six matches so that they are half broken Lay the matches on a dinner plate so that the broken parts meet together Now arrange the half matches so that they radiate in pairs like the

spokes of a wheel (*Picture* 11) If a drop of water is allowed to fall on the centre point the matches swell,



Picture 11



Picture 12

and are forced outwards, to form the pattern of a six-pointed star (*Picture* 12)

The Romans made use of capillarity when in the year 120 A D, they were constructing Hadrian's wall from the Tyne to Solway Firth Whilst the excavations were in progress the workmen encountered a massive rock which their most powerful tools could not break up With indomitable perseverance the Roman engineers set to work to invent a plan for boring the rock After long consideration, one engineer volunteered a suggestion which met with the General's approval and was acted upon immediately Holes were drilled in the rock in as many positions as possible This done, the holes were tightly plugged with wooden spars, and then a quantity of water was poured over the wood The water soaked into the wood by capillarity, and caused it to swell with such force that, after two nights, the rock broke into

fragments A similar method, known as "water plugging," is used for breaking up rock in mines where blasting is too dangerous

Now look around for other examples of capillarity —at home, in the street, and in school

Further Experiments.

1 Place a few grains of powdered dye on the bottom of a jar and cover them with a layer of water six inches deep Leave undisturbed for three days Explain the changes observed

2 Weigh an empty plant pot on a spring balance Soak the pot for half an hour in a tub of water Now wipe the pot as dry as possible and reweigh it How may the differ ence be explained?

3 Fill a canvas bag with mud Collect and examine the liquid which passes through it Pour this liquid into a plant pot, having the hole at the bottom plugged with charcoal Again examine the liquid which collects Pour this liquid through a layer of fine blotting paper in a funnel What name do we give to these processes? What is the result?

4 Try to fill a paper bag with water What happens? Paint the inside of another bag with melted wax Does this bag hold water? Write down your explanation of what has taken place

5 Place a jar of water near a plant growing in dry soil and then arrange a piece of lamp-wick from the water to the soil Note the water level at first and also after twenty four hours Where has the water gone?

6 Stretch a string tightly between two uprights Hang a V shaped piece of wood (made by half breaking a match) over the string Moisten the string with water What happens to the match and why?

4. Why a Ball Bounces.

Let us make a boy s catapult Find a small forked stick and attach an elastic band to both prongs We might strengthen it by inserting a piece of leather in the middle of the elastic band but the simple form will suit us for the present Now we can use it for throwing small missiles, such as stones peas nuts, and paper pellets How is it done? We pull the elastic band and it stretches, we release it and it springs back to its original length with such a force that the missile is shot much farther than we could throw it with our arms Look at the elastic band again First, it is of a certain length, when we stretch it, it increases in length, when we release it it resumes its original form What is it made of? It is made of india rubber and this possesses the property of elasticity Because of this property it is able to return to its former state after being stretched We know many things that can do this—braces, arm bands springs We make good use of this property in the construction of a spring balance where the attraction between the earth and the body to be weighed is the pulling force If it were not for the elasticity of the spring in the balance the pointer would not return to the zero mark on the scale whenever the weight was removed from the hook Stronger springs are often used to ensure the automatic closing of heavy doors and gates Our vocal chords are elastic, and so also is our skin, we can extend them, and after relaxing they resume their original form

Stretching a substance is not the only way of demonstrating its elasticity Let us examine a bicycle pump We see that it has a long piston which can slide in and out of its barrel Inside the barrel there is always air When in ordinary use the pushing down of the piston forces most of this air out through the hole in the end of the barrel Instead of using the pump in the usual way let us close the hole by means of the thumb (*Picture* 13) This prevents any air

Picture 13

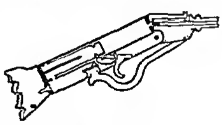
entering or leaving the barrel Now try to push the piston down the barrel Is this an easy or a difficult task? It is certainly more difficult than when the hole in the barrel is not closed Does the piston move at all? Yes, the piston moves a short distance down the barrel What has happened to the air within the barrel? None of it has escaped because the only exit is closed by the thumb Therefore, this same air must be enclosed in a smaller space than it was before the piston moved Because this change has been brought about by the pressure of the piston we say the air in the barrel has been compressed The air is compressed only whilst the piston remains pushed in the barrel When we release the handle we withdraw the compressing force What happens? The piston flies

back rapidly to its former position The reason for this is that the air within the barrel has regained its original volume

We see a similar effect when a conjurer wishes to "vanish a large silk pocket handkerchief He rolls the handkerchief into a small ball and squeezes it into a very small space by compressing it with the muscles of his palm So long as he *maintains this pressure* it is small enough to be concealed but when the conjurer gets to that stage in his performance when he wishes to produce it again he must withdraw the compression To do this he relaxes the muscles of his hand and the handkerchief at once returns to its original size Without any knowledge of sleight of hand we can produce similar effects by using a sponge or an elastic band

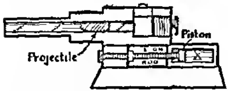
Substances which take up their original shapes after compression are said to be elastic that is to possess the property of elasticity Clay cheese, and putty are compressible but they are not elastic, since they keep their new shape when the pressure is removed

The bicycle pump the buffers at a railway terminus pneumatic devices for closing doors, shock absorbers in heavy artillery guns, and the compression chamber in an air gun (*Pictures* 14 and 15) all depend for their satisfactory working upon the great elasticity of air They all comprise a cylinder filled with



Picture 14

air and, as we have seen, this air can be compressed by a piston, but it regains its initial dimensions when the pressure on the piston is withdrawn. A similar effect is found in the pop gun.



Recoil of gun pushes piston farther into Cylinder at X greatly compressing the air contents

Picture 15

In this case the air, after compression, forces out the cork from the end of the tube in order to return to its initial volume.

The elasticity of air, as shown when under compression, was first investigated by Robert Boyle in 1662. This English chemist is often spoken of as "The Father of Pneumatics,' on account of his discoveries. In one of his earliest experiments he used a large spherical glass globe into which air could be forced (*Picture* 16). With this apparatus he was able to show that the volume of air decreases as the pressure on it increases, which is just what we discovered in our experiment with the bicycle-pump. We may express the results of Boyle's investigation by saying that the volume of air varies inversely as the pressure if the temperature remains constant.

Picture 16.

This is a statement of **Boyle's Law.** It tells us, for

example, that if a gas has a definite volume when under a certain pressure, then when we increase that pressure eight times we at once decrease the volume of the gas eight times. Decreasing the pressure on a gas has the opposite effect on its volume. Boyle gives us his own explanation in detail. He says, that when the air springs back to its original volume on account of the pressure being removed, the air particles behave like minute sponges or the hairs of a fleece of wool. As we know, these substances are very elastic, and regain their original shape almost immediately after any compression of them is withdrawn. Consequently he named this property "The Spring of the Air."

We can illustrate this "spring" of the air in a very simple manner. Pour water into a bottle until it is half full, and then hold it in such a way that it can be blown into very strongly. After blowing into the bottle close the open end quickly with the thumb. The bottle is now half full of compressed air, which is very elastic and tends to regain a larger volume. Tilt the bottle so that the water fills the neck of the bottle. Now slip the thumb back a little so as to form a small exit, and it will be found that the pressure of air, due to its great elasticity, will force out a long jet of water as if it were issuing from a soda siphon (*Picture* 17).

Picture 17

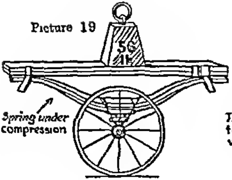
The following interesting experiment provides us

with an ingenious application of the elasticity of air. Having placed a threepenny piece on a smooth table let us propose to our friends that they are to raise it without touching it in any way Of course they will doubt that this can be done, but, by holding a half-open hand about three inches behind the coin, and blowing with a sharp vigorous puff just in front of it, the three penny piece will leap up in the air and may be caught in the waiting hand (*Picture* 18) This is because, when we blow, a jet of compressed air is forced under the coin, and the expansion of this air, due to its elasticity, causes the coin to leap from the table

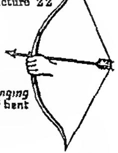
Picture 18

All boys and girls love a bouncing ball, but no ball would bounce were it not for the elastic properties of the materials composing it When we throw a rubber ball against a white washed wall it rebounds and may be caught If we examine the surface of the ball we find that a considerable portion of it has been in contact with the wall, as is shown by the white circle it now carries To mark the ball in this way it must have been flattened against the wall by the pressure of the impact and, following this compression, the elasticity of the rubber and the air inside it caused it to regain its former shape and rebound A hollow india rubber ball which has been pierced with a needle

Picture 19

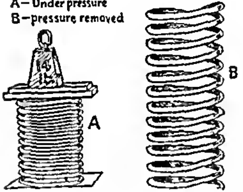


Picture 22



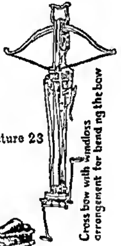
Picture 20.

A— Under pressure
B—pressure removed



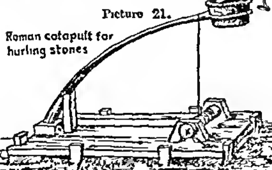
Elasticity du. to compression

Picture 23



Picture 21.

Roman catapult for
hurling stones



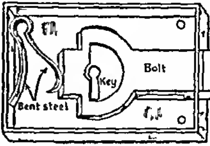
ELASTICITY BY BENDING Some Appl cations.

does not bounce so well as an unpierced ball, because the air within is not compressed so much by the impact, but escapes through the hole In unburstable balls the outer sphere of rubber encloses a core of india rubber sponge which retains its elasticity after the covering sphere has been punctured All bouncing balls must be made from elastic material, hence the use of glass for marbles and ivory for billiard balls No one would think of using balls made of putty for a game of billiards!

Without this wonderful property of elasticity, travelling by motor would be a succession of nerve racking jolts Pneumatic tyres, laminated springs (*Picture* 19), and air filled cushions, all of which depend on elasticity for their action, have made motoring comfortable and pleasurable The springs used in the manufacture of chairs, couches, and mattresses show elasticity after compression (*Picture* 20)

It frequently happens that elasticity is demonstrated by bending, as when a boy jumps on the end of a spring board in the gymnasium or at the swimming baths The board bends under his weight, and the recoil, due to elasticity, projects him upwards One of the earliest uses of elasticity due to bending was made by the Romans, who constructed catapults for hurling great stones (*Picture* 21) They fixed one end of a pole securely to a platform, and drew down the free end by means of a rope To this free end was attached a basket in which stones were placed When suddenly released, the pole returned to its

original position, thus hurling the missiles from the basket into the midst of the enemy. Similar devices have since been used for hunting animals and constructing traps. It is the elasticity of the bent steel in a lock which shoots the bolt into position after the key has been turned (*Picture* 24). Much of our sporting apparatus depends for its operation on elasticity by bending, as in the case of a fishing rod when the fly is thrown, of a golf club when the drive is made, of a cricket bat when a good stroke is played, and of the archer's bow when the bow string is released (*Picture* 22). Cane and willow, on account of their elasticity, are commonly used in making these requisites for sportsmen. In crossbows such as were used in the battle of Crécy the bending of the bow was accomplished by turning a small windlass which enabled the bowman to bend his bow more than was possible by using his hand alone (*Picture* 23). When the wind causes the tree tops to sway and the corn and tall grasses in the fields to be blown aside, what follows? They regain their upright position after the breeze has passed because of their elasticity.



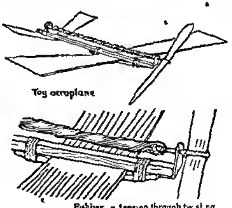
Picture 24

The action of a clock spring and of the hair spring of a watch illustrates the elastic property of a metal when bent into a coil.

Substances show varying degrees of elasticity when they are twisted Scientists speak of this as torsion, but the principle was known long before this name was given to it In certain parts of Scotland the method used for roasting meat in front of a fire has been handed down for generations (*Picture* 25) It consists of hanging the meat from a hook suspended on a wire, which after being twisted, continues to untwist and twist again, thus turning and turning the meat till it is perfectly cooked all round

Picture 25

Boys often make use of torsion to rotate the propeller of a toy aeroplane (*Picture* 26) To do this the propeller is attached to a few strands of india-rubber which are tightly twisted, and which, when released, untwist in the opposite direction thus causing the propeller to rotate at a rapid rate



Picture 26

As we walk to and from our homes we may observe many more examples of elasticity. It is interesting to determine whether a body returns to its original form after being extended or pressed, or bent or distorted.

Further Experiments.

1. Round an egg cup, which is standing on a thick cloth, arrange four discs—one of bone, one of ivory, one of celluloid, and one of iron. Using the bone blade of a paper knife, press the edges of the discs in order. Which discs jump to the egg-cup, and why?

2. Obtain a metal tube into which a thin pencil will slide. Press the tube into a potato and then withdraw it. The tube now has a plug of potato in it. Do the same with the other end. Using the pencil as a piston rod, force one plug up the tube. Explain what happens to the other plug.

3. Fill a punctured ball with water. Will it bounce? Empty the ball of water and allow it to fill with air. Again try to bounce the ball. Repeat the experiment, having closed the hole in the ball with wax. How do you explain your observations?

4. Strike the prongs of a dinner fork smartly against the table and at once touch a glass tumbler lightly with them. What do you notice? Do the same with a wooden fork. How may the results be explained?

5. Pass a string through two holes in a button and tie the ends. Loop the string over the thumbs, having one on each side of the button. Then twist the string tightly by twirling the button. Release the button and observe what happens. How does pulling outwards with the thumbs affect the disc? What do you infer from this?

6. *Drop a rubber ball and a ball of clay on to a layer of* chalk dust. What happens? Examine both balls and explain your observations.

5. Why Things Fall.

At any moment of the day, at whatever place we may happen to be, whatever we are doing, we may ask many questions about the things around us, and these questions may puzzle even those who are very learned Many people, of course, do not pause to think why things happen as they do Having just arrived home after his day's work, and ready to enjoy a well-earned meal, a man takes out his latch-key, places it in the lock and gives it a turn Then he pushes the door and it opens He enters the house, closes the door, takes off his hat and overcoat, hangs them on hooks, turns the water-tap, washes his hands and face, and so continues to do many other things with which we are all so familiar Most of them are repetitions of what he has been accustomed to do for as long as he can remember Think over our own various actions At nearly every stage we are moving, or at least trying to move something When we turn the key in the lock we move the bolt, when we push the door we move it on its hinges, we move our arms, our legs, our bodies when walking, we move our hats and boots from place to place, and so on Our imagination may extend the list much further Now, what exactly were we doing to the bolt of the lock? Many answers, all with more or less the same meaning, come into our minds Let us say we forced back the bolt of the lock That certainly sounds simple, but what do we mean by the word *forced*?

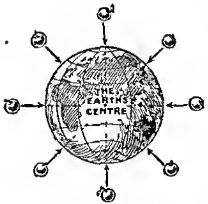
Notice (1) we tried to move something, (2) the thing we accomplished was the movement of something This leads us to the conclusion that force means *moving or trying to move something* It would be quite correct to say that by means of the door-key we exerted a force on the bolt of the lock, and we may go further and say that *force is that which produces, or tends to produce, motion in a body*

How many forces there are in the world it is quite impossible to say Let us call to mind a few of them There is the force which causes an electric car to move, there is the force which keeps a kite flying, there is the force which drives a ship, another which floats a ship, another which moves the piston of a steam-engine, and a force which causes things to fall

Why do objects fall? Those who have been to a circus must have laughed at the foolishness of the clown who pretended to hang his hat on a pole where there was no peg Of course his hat dropped to the ground That is just what we expected, for we have learned by experience that things with no support fall Now imagine what would happen if at the bottom of the circus pole there had been a pit. The hat would have fallen lower and lower until it reached the bottom of the pit Let us ask ourselves what would be the result of deepening the pit Would the hat fall to the bottom however deep the pit might be?

Things which have insufficient support fall This is a rule which applies to the deepest pit in the world' Consider what would happen if a pit could be made

straight through the earth, say from England to Antipodes Island, and a piece of iron dropped into it from here Scientists are of the opinion that in the absence of air or other resistance, the iron would move towards the earth s centre with increasing speed, but after passing this point its speed would decrease as it moved towards the other end of the pit From Antipodes Island it would return towards England, gaining its greatest speed again at the earth's centre If, however, air were present, the piece of iron would make shorter and shorter journeys backwards and forwards past the earth's centre until it would come to rest at this point We may conclude that all unsupported objects are drawn towards the earth's centre



GRAVITATION
The apple falls towards the centre from every direction

Picture 27

So, if you throw an apple up into the air it comes down in a direction, which, if continued, would pass through the centre of the earth

We speak of this effect as gravitation, and gravity is the force which tends to make all bodies move towards the earth's centre

We must not assume that the force of gravity acts with reference to the earth only Wherever there is matter there must be gravitation The greatness of this attraction depends upon the

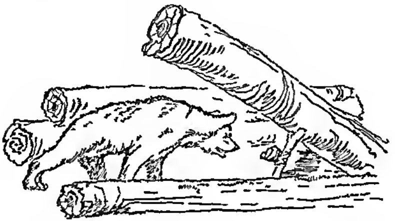
amount of matter in the objects and the distance they are apart This is known as the Law of Gravitation

The same force that causes a stone to fall to the earth helps to keep the moon in her orbit and also to keep the planets in their paths The knowledge of the effect of gravitation led astronomers to discover the planet Neptune They had previously noted that Uranus was moving in a path they could not satisfactorily explain. They became convinced that some unknown influence was being exerted, they made new calculations, and, as a result, further search revealed the presence of the planet Neptune

Near the surface of the earth we are made aware of the earth's gravity, because it is so much greater than the gravity of other objects that are near to us If a penny is held above the ground the earth attracts the penny with much more force than the penny attracts the earth, and if we release our hold on the coin the penny falls to the earth, but to a very, very small degree the earth also tends to fall to the penny

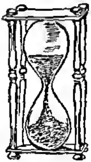
It would be interesting to write down all the uses we make of this force of gravity and all the devices we adopt to overcome its action The subject was investigated only after the effect of gravitation had been known for centuries It is said that a great student of science, named Isaac Newton, was one day sitting in his mother's garden when he saw an apple fall from a tree He asked himself, "Why does an apple fall?" and he did not rest until he had found a satisfactory answer to his question

Years previous to this, trappers in Canada had applied the force of gravity to the making of traps for game, by arranging a falling log, which was freed



Picture 28

by pulling at the bait (*Picture* 28) Hour glasses with grains of sand falling from one globe to another (*Picture* 29), sinkers for fishing lines, portcullis gates in old castles plumb lines, clock weights, ballast for ships, the bucket lowered down a well, the cage in a mine shaft, and many other useful devices depend upon this important force



Picture 29

Although the force of gravity is so useful to man it is not an unmixed blessing for he has had to contrive ways and means to counteract its influence For instance, in building processes, pillars are used as supports in order to resist gravity Pit props, tunnel supports, bridges, girders,

bearings in wheel hubs, tables, chairs, shelves, railway sleepers, hooks, pegs, and telegraph poles are examples of man's inventions to counteract this force

After what we have said we could hardly imagine a world without this force acting, but it is none the less true that a few years ago a Frenchman spent much time and energy in trying to produce a screen which would cut off the effect of this force It goes without saying that he did not succeed Probably he saw that the disadvantages of such a screen would outweigh any advantage that might be gained Can we imagine what it would be like to live on our earth without *this force of gravity? If it were possible to get rid* of it we should be able to raise our arms without effort, and they would stay at the point to which we raised them, very much after the manner of a jointed doll We could climb without using a ladder, we could throw a ball into the air, and it would go up and up for miles and miles and never come down again, we should need neither table nor chairs, and our tea-cups could not fall and break But this is a very questionable advantage when we consider that the tea could not be poured into the cups, for it would not leave the teapot. Truly the Mad Hatter's Tea Party, at which Alice was a visitor in Wonderland, was a sane affair compared to the happenings in a world without gravity Of course, this is only imagination, for without the aid of gravity our hearts would cease to work, our world would fly off into space, and the rest is better imagined than described

Further Experiments.

1 Throw a dart vertically upwards into the air Allow it to fall and stick in the floor Test the angle the needle of the dart makes with the horizontal floor Repeat the experiment To what conclusions does this lead you?

2 Make a target by cutting a hole in a large sheet of cardboard Place the target ten feet away, and with a peashooter take aim at the centre of the hole Shoot peas, and notice where they strike the target Where must the tube point if the peas are to go through the hole? Test your theory

3 A bird-cage is to be fixed eight feet above the floor of a room Design four methods of support and show how each method overcomes the force of gravity

4 Given two empty match boxes, construct a model mouse-trap which depends on gravitation for its action

5 Arrange a pile of draughtsmen like a pillar. Using a piece of cardboard, a button, and a piece of thread, how can the sides of this pillar be tested to ensure that they are vertical?

6 By strings attached to a rigid iron bar* hang two balls, one of iron and one of pith Arrange that their centres are in the same horizontal line and the surfaces separated about half an inch Set the iron ball swinging so that it does not strike the pith ball Observe what happens to the pith ball and explain the result

6. Why Things Are Heavy.

If we were asked whether we would prefer to carry up a steep hill a sack full of wood shavings, or a similar sack filled with iron turnings, most of us would select the sack of shavings for our load If we had to give a reason for our choice we should say it was because of the difference in weight This is a very sane reason, for no one but a professional "strong man" would be keen to carry great masses, and even he might not do so unless, perhaps, compelled by circumstances

When we try to lift an object there is always a tug-of war between our strength and the pull of the earth, or gravity, as we have learned to call this force Sometimes we easily win in this tug-of war, as, for instance, when we lift a feather from the floor, but at other times we lose rather badly, as is the ease when we try to lift a large bag of coal

In a boys' tug-of-war the victory goes to the side which pulls the flag on the rope towards it, and in the tug of-war, Earth *versus* Self, the victory may be said to go to that side to which the object moves

When we have been engaged in a tug of war we are always ready to "explain" the result whether our side has won or lost Let us try to explain the result in the tug of-war against gravity If we are on the winning side we say that the body we pulled had not much weight, and, on the contrary, if we failed in our effort we explain the situation by pointing out

the tremendous weight of the object All this means that we are measuring the greatness of the pull of gravity and calling it weight

Every boy knows that there are devices which count in a tug of war such as having the heaviest man at the end of the rope Let us try to make our victory against gravity surer by adopting a little device We have seen how gravity pulls everything towards the earth s centre It is also found that outside the earth's surface the nearer the body is to this central spot the greater is the earth s pull on it Equally certain is it that the farther the body is from the centre of the earth, the less is the force of gravity exerted on it Here then is the clue to an arrangement by which we may score a point against gravity The pull of gravity is weaker on the top of a very high mountain or up in an aeroplane than it is on the same object at the seaside If we can arrange, therefore, to have our tug of war against gravity at a great height above sea level we shall have a better chance of winning, for we shall have less weight to overcome Were the earth all of the same density—which it is not—and were we to compete down in a deep mine, the attraction of the earth's crust above us would reduce the effect of gravity by acting in the opposite direction, and so we would gain an advantage

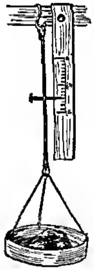
Let us make a strict condition for our tug of war Let us bind ourselves to pull against gravity always at sea level It would appear that in doing so we are ruling out all chance of gaining advantage for

ourselves, but there is still opportunity for us to benefit by selecting a suitable position. At school we have often seen maps of the world drawn on the surfaces of globes, and we have learned that the shape of our earth is spherical. This, however, is not strictly correct, for the earth bulges a little at the equator, and has a more flattened shape at the poles. Because of this variation from the form of a true sphere, some points on the earth's surface are nearer to the centre of the earth than others, and because of this the force of gravity varies at different places. If we compete against gravity at the equator, the pull we have to overcome is less than if the competition takes place near the North or South Pole. The advantage we gain by this means is not very great, for at the most liberal estimate it would mean a reduction of not more than $\frac{1}{191}$ of the weight of the object concerned.

Every object on the earth, in the seas, and in the sky must have some weight, no matter how small or how large it may be. This is because the earth attracts all objects, from the smallest speck of dust to the heaviest boulder, and this pull is always in the direction towards the earth's centre. The only particle of matter of which the earth is composed which could be said to possess no weight would be some infinitely minute speck when situated at the earth's centre.

Mr H G Wells tells a story of an imaginary Mr Pyecraft, who was very fat, and who took medicine made from a Hindu recipe in order to cause *loss of*

weight The result was startling He floated like a gas filled bladder Had it not been for the ceiling he could not have remained in the room His friend helped him to get under a solid mahogany table, and this enabled him to keep on the floor Had he gone outside he would have had no need for an aeroplane! What was he to do? His friend suggested that he should have his meals on the top of the bookcase! At last it was arranged that he should wear lead underclothing and lead soled boots, lead discs were sewn inside his clothes, and he carried a bag of solid lead Of course all this is imaginary But it would be a dreadful thing to lose one's weight, would it not?



Picture 30

We can devise means to measure the weight of a body, *i e*, to find how much it is pulled towards the centre of the earth by this wonderful force of gravity One of the simplest means is to take a piece of india rubber, such as boys use for catapults, about two feet of wire the lid of a coffee tin, some thread, a nail or two, a pin, and a strip of plasterer's lath With the nail we punch a few holes in the rim of the tin, and, using the wire, we convert the lid into a kind of hanging basket This we tie securely to one end of the rubber, and fix the free end of the rubber to a shelf (*Picture* 30) The pin is now pushed through the rubber, so that it projects

as an indicator against the piece of lath, which we fix upright by the side of the rubber Having marked the lath at the place where the pin is pointing we are ready to begin weighing We borrow from the kitchen a pound weight, *i e*, a lump of iron which is attracted to the earth's centre by gravity with a pull we have decided to call one pound This iron weight, when placed in the lid, causes the rubber to stretch, and the position of the pin is again recorded on the lath, and labelled *1 lb* We can now remove the weight, and the pin will move back to its original position If we repeat the weighing, using a half pound weight, we find that the pin now stands half-way between the first mark and the 1 lb mark It readily occurs to us that, if we divide each of these two equal spaces into eight equal parts, each of these small parts will represent an ounce weight We are now able to use our arrangement to find the weight of objects not greater than one pound From the garden we select a stone whose weight we wish to determine If we place it in the lid, the earth's pull will be registered by the position to which the pin moves For instance, if the pin stops at the twelfth mark down the scale, counting the first as zero, we are safe in concluding that its weight is twelve ounces Other loads in the lid cause different extensions of the rubber up to a certain point, beyond which the elastic band becomes strained Until this point is reached the ratio of the weight to the extension it causes is always the same

The principle upon which this method of determining weight is based is known as **Hooke's Law,** because Hooke was the man who discovered it. Hooke was a poor scientist who experimented for a long time in order to prove the truth of this law He used many different substances in place of india-rubber, which did not give very good results after a few weeks The india-rubber lost its elasticity and became worn out The best results were obtained by using a spiral spring of steel Let us substitute for the rubber of our previous experiment one of the spiral spring arm-bands sold by gentlemen's outfitters

Now we have a contrivance by which we may measure accurately for many months the weight of articles like letters and books

There are other means of ascertaining weight which do not depend upon springs but upon levers Some of these are constructed so carefully that the smallest object may be weighed very accurately We shall consider these later

Further Experiments

1 Place a string over the smooth backs of two chairs arranged near to each other On each end of the string hang an empty coffee tin, so that the string is stretched At the mid point of the string attach a paper pointer Add six marbles to one side Which way does the pointer move? Now add ten marbles to the other side and explain the difference you observe

2 Take a portion of a clock spring bent almost into a circle Pull the ends apart What relation holds between the distance the ends are apart and the strength of your pull? Could you use such a spring to make a Spring Balance?

3 Nail a light wooden lath so that it projects over a shelf and has its free end near a vertical ruler Place various weights separately on the free end Record your observations and explain them

4 Nail two upholsterer's springs between two boards Measure the distance between the boards Put the boards flat on a stool and sit on the upper board Again measure the distance What has happened? What do you expect would be the effect of an adult sitting on the board? Test your theory

5 Hang various weights, one after another, on the bottom of a spring roller blind Measure the distance each weight draws down the blind Hang a stone on the blind What is its weight?

6 Fix a fishing rod upright in the ground Tie a canister on the end of the line Load the canister with marbles, one at a time What happens to the rod? Ask a friend to place in the canister some marbles of which you do not know the number Can you calculate this unknown number?

7 Release the lid of a "Jack in a box" What happens? Why? Find, by experiment, the least weight which, when placed on the lid, will keep it closed

8 Make a light spring by wrapping thin copper wire in close coils round a cylindrical pencil and then removing the pencil Use this spring to construct a spring balance suitable for weighing letters

9 Suspend three similar india rubber bands of equal length from a horizontal shelf Attach hooks to their lower ends, and hang suitable equal weights from the hooks What do you observe with regard to the lengths of the india rubber bands? Repeat the experiment, substituting a cotton string for one of the bands What inference may be drawn from your observation?

7. Why Things Stand Up.

Why is the handle of a cup or a jug or a teapot fastened to the side of the utensil, whereas in the case of a bucket the handle is so placed that it may be raised above the level of the liquid contained in the bucket? Of course, the handle of the bucket enables us to pull upwards *directly* against gravity We find such a position necessary to enable us to raise the bucket and its contents with comfort We can grip the handle of a cup of milk, a jug of coffee, or a pot full of tea, and, in this position, we can counteract the force of gravity easily because the weight is comparatively small—smaller than, say, the weight of a two-gallon bucket full of water

Consider the case of a bucket filled with water which we wish to raise so that the water surface does not vary too much during the raising We know that the water in the bucket is made up of a very great number of drops, and that the bucket too consists of innumerable particles Each of these particles is attracted to the earth by the force we call gravity Although these forces are so many in number it is found that there is one fixed point where the total weight of the bucket and the water acts This is equivalent to saying that all the forces acting on the bucket and its contents have the same effect as one force would have when exerted at this particular point Let us try to discover exactly where this point is situated That is to say,

where is the point at which we must use *our* force when we wish to raise the bucket?

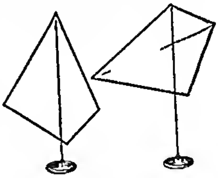
Before answering this question let us find answers to two other questions First, if we wished to raise a disc by means of a piece of string, and at the same time keep the disc horizontal all the time—just as we keep the water surface horizontal in the bucket—at what point should we bore the hole through which we should pass the string and knot it? The answer is *through the centre* of the circle

Second if we had a sheet of metal in the form of a rectangle, or a triangle, or any regular figure instead of a disc, which point should we find through which to pass the string? The answer is as before through *the middle point*

Now let us return to the question as to the exact point at which we must use our force in order to raise a bucket filled with water It is evidently in a line perpendicular to the centre of the bottom of the bucket This tells us that the point where the total weight acts is somewhere along this line The exact position is higher or lower according to the amount of water in the bucket

Scientists call this point the centre of gravity, and they tell us that every object on the earth has such a point It has been found that the centre of gravity is a fixed point, which can only be altered in position by altering the form of the object This explains why the centre of gravity of a bucket of water varies with the amount of the water

We have seen that the centre of gravity of regular plates is always the mid point, and because of this it may be determined by geometry. In the case of irregular figures this method cannot be applied so easily, and the centre of gravity is best determined by experiment. Cut out of cardboard an irregularly shaped piece of which the centre of gravity is to be determined. Prepare also a strong pin from which hangs a heavy button by means of a thin thread. Push the pin through the card near to the edge. Now arrange to support the card so that it can turn easily, and also so that the thread rests close up to the face of the card (*Picture* 33). Using a ruler, trace a line on the card where the thread touches it. Now change the point of support, as shown in the picture, and again trace the direction of the thread on the cardboard. The two lines are both lines through the centre of gravity, which must therefore be situated at the point where the lines intersect.

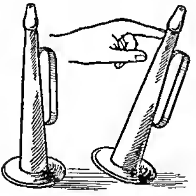


Picture 33

If we can arrange to support a flat object at its centre of gravity, it will balance there. We can easily prove this by placing our irregularly shaped cardboard with its centre of gravity resting on the point of a needle. Perform a similar experiment with an ordinary

postcard having determined its centre of gravity by drawing its diagonals Does it balance? Yes, because its centre of gravity is also its geometrical centre This explains why the knob is always placed at the centre of a pan lid and why a wheel will balance at its hub

We can see that it will be impossible to support every object just at its centre of gravity For example, we cannot support a block of wood, nor a bucket of water, nor a wedding ring at its centre of gravity Such objects will balance only when they are supported at a point on the imaginary line joining the centre of gravity to the earth's centre This is by no means an easy task, for the slightest disturbance will destroy this balance, as every boy who has tried to support a walking stick upright on his chin can understand



Picture 34

Take a child's tin trumpet, and try to make it stand upright with the mouthpiece touching the table top It is not easy to do this Most of us fail in the attempt But if we invert the trumpet, the task is as easy as can be (*Picture* 34) Why is this? We say that the trumpet now rests on a wide base and thus it remains quite stable **Now,** whilst the trumpet is

standing in this position give it a slight push at the mouthpiece Even this does not disturb its balance permanently Now press at the mouthpiece gently with the finger, either to the right or to the left, and notice exactly how far it has to be moved before the trumpet topples over If we do this carefully, we shall see that the trumpet falls over when the imaginary line—from its centre of gravity to the earth s centre—falls just outside the supporting base

When the trumpet stands on the table and no pressure is exerted sideways it will not topple over, and the trumpet is then said to be in stable equilibrium This fact explains why the Pyramids of Egypt do not fall why a milk can sent by rail is made wide at the bottom and narrow at the top, why a factory chimney is tapered upwards, why a candle is safer in a candle stick than resting directly on a shelf, and why a church steeple always rests on a broad foundation

Many little experiments can be performed to illus trate this principle We can place a dinner knife with the blade projecting over the edge of the table, and it will remain steady if the handle is resting on the table top But when we place the centre of gravity away from the support of the table, as, for instance, when we place the blade only on the table, the knife falls We can easily blow a small bottle over when it stands upright resting on a narrow neck, although we blow against it in vain when it is standing upright on its base

In the town of Chesterfield there is a church spire

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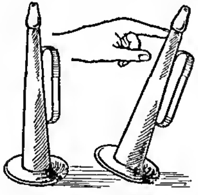

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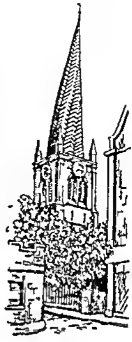
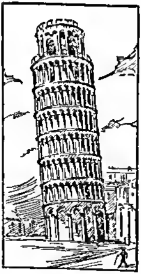
In the town of Chesterfield there is a church spire

which leans about seven feet to the south and four feet to the west (*Picture* 35) The people of Chesterfield were once very anxious about the safety of this crooked spire, which certainly appears dangerous to the passers by Their fears were allayed by a clever architect, who calculated where the centre of gravity of the slanting spire was situated, and showed that it was vertically above the foundations It will remain quite safe therefore until something further happens to move the centre of gravity outside its base of support



Picture 35



Picture 36

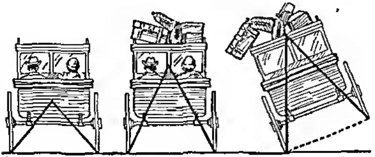
The famous Tower of Pisa is another example of how a leaning building is quite stable if its centre of gravity is above and within its base (*Picture* 36) We must not assume that an object can stand erect only when it rests on a great part of its own surface In the case of chairs and tables in a room, only four points rest on the ground, but the objects are stable whilst the

centre of gravity is always vertically above the area which would be traced out by lines joining these points This is why three very slender legs of a camera tripod, or three stout staves joined at the top and arranged as a tripod, will bear a great weight (*Picture* 37) This also gives us a reason for the stability of a three legged stool When we ourselves stand up with our feet together, the centre of gravity of our body must be above the area enclosed by a line drawn round our feet If we stand with our left shoulder and left foot against a vertical wall, we cannot raise our right foot sideways so long as our left foot and shoulder keep in position Try this and then search for the explanation

Picture 37

Consider the case of an empty four wheeled cab on a level road If it stands upright, the vertical line through its centre of gravity must fall within a line traced round the points where its wheels rest on the ground (*Picture* 38) When heavy luggage is placed on the roof, the centre of gravity is raised If the cab now runs on a sloping road, a slight jerk may easily upset it, by causing the centre of gravity to fall outside the area of support. Loading the inside of the vehicle

with passengers lowers the centre of gravity, and makes it more difficult to upset the cab Even on a sloping



The centre of gravity altering according to differences in position of load.

Picture 33

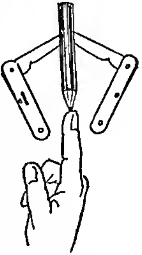
road the cab will now be more stable, because a greater disturbance is necessary to bring the centre of gravity outside the area of support

The raising or lowering of the centre of gravity by the loading of an object alters the balancing point

We have learned how to stand up straight and keep the centre of gravity of our bodies above the base of support We learned this, without knowing we were doing so, when we were quite babies Later in our lives, when we began to carry heavy things, we found also that we had to lean away from the side on which we carried the weight to keep the new centre of gravity above and within the base (*Picture* 39) Did the load we carried raise or lower our centre of gravity?

Picture 39

We can take advantage of the alteration of the centre of gravity by loading an object to make some very amusing toys For example, we may undertake to balance an ordinary blacklead pencil, point downwards, on our finger tips, although our friends may try to do so in vain The secret is that we must stick two half open pocket knives into the pencil, and this brings the centre of gravity of the combination below the point of support, thus keeping the pencil upright (*Picture* 40)



Picture 40

A similar reason explains how a doll may be made to stand upright on two legs and may even be made to bow to an audience To do this we require a small doll, having legs without joints firmly attached to the body Bend a piece of iron wire to form three sides of a rectangle and drive one end firmly into the body of the doll (*Picture* 41) Weight the other end of the wire by a piece of lead or a heavy block of wood The doll will now balance quite easily on its legs when placed near the edge of a table, and if we disturb it slightly by pushing it, we find that it returns with a swing to its position again, so that it appears to be bowing to the spectators.

Picture 41

It is said that Columbus succeeded in balancing an egg on its narrow end—but he flattened this end by tapping it on the table and cracking the shell It is almost an impossible feat, if it is to be done with an ordinary egg and the shell is to remain unbroken Still, we can make for ourselves an egg which will easily balance on its narrow end on almost any surface Thus pierce two small holes in the shell, one at each extremity, and then remove the contents by blowing Now seal up the narrow end with a little plaster of Paris, and, when quite dry, pour into the egg through the other hole a mixture of sealing-wax powder and lead filings Hold the egg upright, and bring the mixture to the closed end of the shell Then, warm this closed end over a lighted gas jet and the wax will melt On cooling, the lead and wax will become solid within the narrow end of the egg, and the centre of gravity is now at a point very near to this end On sealing up the wide end we find that the egg will stand in an uprigbt position on its narrow end (*Picture* 42) In fact, it will be found difficult to make it take up any other position!

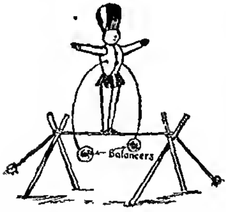

Picture 42.

We can amuse and, perhaps, mystify our friends by showing them a cardboard bottle shaped tube, which will lie quite horizontally on the palm of *our* hand, but which *they* probably cannot bring to rest in any but an upright position on *their* hands We must

prepare a small cardboard tube, and close it at one end with sealing wax powder and lead in the same way as we previously prepared the egg It is advisable to make this end as wide as possible and to round it off (*Picture* 43) This tube will now stand upright, and will refuse to remain in any other position But, when we take hold of

Picture 43

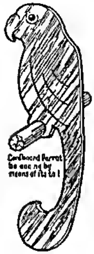
the tube we secretly slip a heavy brass nail or piece of wire into the open end—thus altering the position of the centre of gravity—and the tube now lies horizontally on our hand We must take care to withdraw the nail without being seen before we offer the tube for the attempts of our friends



Picture 44

At country fairs men often give exhibitions of skill in walking on a tight rope It is a very difficult feat, because the performer has to keep his centre of gravity vertically above a very narrow base It would be almost impossible to do this if the man on the rope did not use a long,

heavy pole, which he can move about so as to adjust the centre of gravity whenever he feels himself about to overbalance We can balance a doll on a clothes line by the same method, thus Push a semicircular wire right through the body of the doll and weight each end of the wire with lead (*Picture* 44) Many variations of this trick are possible For instance we may cut out the shape of a parrot from cardboard in such a way that the point of its tail will lie in a vertical line drawn downwards from its head (*Picture* 45) Then the parrot will perch on a string, or a rod, or a finger quite easily



Picture 45

There is an infinite number of bodies around us Some of these are standing quite firmly and others are not Remember that the inquiring mind is always searching for the why and the how It is interesting to make sketches of various objects, and then to estimate the position of the centre of gravity Try this with a chair, a table, a pen, and so on, and each time test your estimate as far as you can

Further Experiments.

1 Four horses are necessary to pull a heavy plough Design a method of yoking them so that each horse does an equal share of the pulling

2. Stand twenty dominoes on their narrow end at intervals of one inch Push the top of one of the end dominoes towards the next one Explain what happens

3 Take a comb with teeth of equal size On which tooth or teeth will the comb balance, and why?

4 How may a florin be held upright between the points of two pins? Blow on the coin What happens?

5 Attach a metal button to one end of a semicircular wire, and wrap the other end around a match head Place the other end of the match on the top of the finger Repeat the experiment without the button How do you account for the difference?

6 Obtain a pear shaped object, such as ladies sometimes use when darning the heels of stockings Hold it upright on its narrow end on a table Release it and observe what happens Repeat the experiment after standing it on its wide end Explain your observations

7 Blow out the interior of an egg and introduce two or three thimblefuls of fine sand into the shell Seal both ends of the egg with wax. Show how the shell may be made to stand in any desired position How may we make quite sure of this?

8 How a Locomotive Takes Up Water Without Stopping.

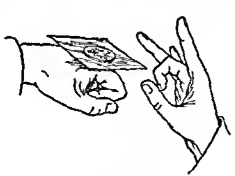
Have you ever heard the story told by Hans Andersen about the dolls in a play box waking up in the middle of the night to hold a dance on the nursery floor? Of course, this is only a fairy tale It amuses us, because it seems so impossible and so ridiculous We know by experience that playthings cannot move of their own accord, and that, once they are put in a certain place they stay there until something happens to move them All inanimate objects, that is, all lifeless objects, stay just where they are placed, wherever it is, until something outside of themselves disturbs them What name shall we give to this property which they possess?

Let us use a word which is often applied to lazy people who refuse to work unless forced Such people are said to suffer from **inertia**—a word which will suit us very well to describe this property of lifeless things when they are undisturbed We may say that the inertia of an object causes it to continue in a state of rest unless it is acted upon by some force

This has been common knowledge since the beginning of man's life on the earth, but it was not until Isaac Newton began to ask, "How and Why?' that the fact was stated

When we leave a piece of paper on the table we expect to find it still in the same place, even after we have left it for hours If we return to the table and find it in a different position we conclude that some one has disturbed it, or that the wind has blown it In any case, its inertia must have been overcome by a force

Let us consider another example of how inertia comes into operation—one which is not quite so obvious as the example we have given of the piece of paper Balance a smooth postcard on the knuckles of the hand so that it rests horizontally Now place a penny on the card just above the point of balance It seems almost impossible to remove the card without disturbing the coin But it is not a very difficult feat to perform Give the postcard a smart horizontal flick with a finger of the other hand (*Picture 46*) The card glides away and the penny remains behind, balanced on the knuckles What has happened? A force has been exerted on the postcard to cause it to move, but the penny, by its inertia, tends to remain at rest and is thus left behind, balanced on the knuckles



Picture 46

In the same way, when a hard ball supporting a

pile of coppers is placed within a circle, which has a diameter rather larger than that of the ball, we may force the ball to move by striking it with a similar ball rolled against it But the force of the impact does not overcome the inertia of the coins, which will always drop within the circle They may roll away after dropping—but that is another matter—they drop first within the circle

Picture 47

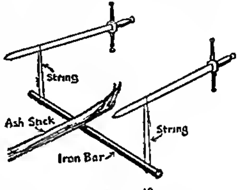
Another similar device is to balance a pile of six pennies on one elbow, having the wrist resting against the shoulder, and then, by smartly dropping the wrist, all the pennies may be caught in the palm of the hand (*Picture* 47) It is because of inertia that a dog, by jerking its head back sharply, can catch in its mouth a lump of sugar which it has held on the tip of its nose (*Picture* 48) Perhaps we all know many other similar phenomena which depend upon inertia

Picture 48

Why is it that a heavy carpet hung from a line is almost stationary, even though we give it many hard blows with the carpet beater? It is due to inertia that a curtain of weighted strings protects a person standing a foot or so behind it, when another person, armed with

a walking stick, strikes from the opposite side of the curtain

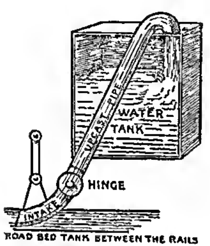
It is said that the following feat was once performed before King William I A strong iron bar was hung by strings looped over two swords held horizontally (*Picture* 49) A smart blow with an ash rod was struck at the middle point of the iron bar, which broke in pieces, and yet the string was not cut by either sword A strong iron bar broken by an ash rod! Yes, because by its inertia the iron bar, which was quite at rest, did not move as a whole and consequently it fractured at the point where the strain was applied •



Picture 49

The inertia of things is sometimes very convenient for us The farmer, when mowing relies on inertia to cause the grass to drop where it has grown, instead of following the line of motion of the mowing machine. Because of the inertia of the cream on the top of the milk, the dairymaid can skim it off very readily The labourer is able to shovel up the coals because they themselves resist moving and allow the shovel to pass under them easily A similar reason the action of the grocer's scoop in flour and the bricklayer's trowel in mortar

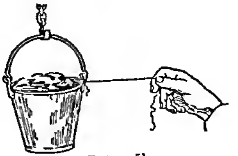
Inertia is used to enable a locomotive, whilst it is in motion, to feed itself with water Water is held in long, narrow tanks between the rails, and as the engine approaches the tank the engine driver lowers a pipe connected with the water tank of the engine This pipe dips down just below the water surface in the tank, and it is thus pushed through the water which tends to remain stationary As the pipe rushes along at a great speed the water is piled up" the pipe until it is discharged into the water-tank (*Picture* 50) This has been an important invention in the history of railways, because it has made possible long non stop runs for engines of great capacity



Picture 50

Although the railway companies make such good use of inertia in this way, they find that inertia is at times a very great disadvantage to them Two very simple experiments will show us why this is so First Hang a heavy object, say a bucket of sand, from a cord or chain, and then tie a length of cotton thread to the ear of the bucket (*Picture* 51) A sharp pull at the thread does not disturb the bucket but it breaks the thread instead Why is this? Second Take hold of the handle of a garden roller and pull

horizontally We find that the hardest work has to be done when we are trying to start the roller The reason is that, besides the ordinary pull necessary to move the roller, we have to use extra energy to overcome its inertia



Picture 51

In the case of a railway engine the resistance to motion is thousands of times greater than in the case of the garden roller This means that the extra force necessary to start a locomotive will be many times greater When the engine driver wishes to start his engine, he must therefore burn more coal to increase the steam pressure than he finds necessary when once his engine is in motion It will be clearly seen that the overcoming of inertia many times during the day affects the cost of the upkeep of our railways Think out how this applies to the tramway systems of our towns and find out the reasons why there are definite stopping places for the trams Does this account for other difficulties which we see occurring in the streets? Yes, it explains why the driver of a horse and cart has to urge the animal to greater effort to start the cart than to keep it in motion Once the cart is moving it tends to keep on moving If we consider carefully then we see that this inherent property of matter which we call inertia is two sided, thus—(1) when

matter is at rest it tends to remain for ever at rest, and (ii) when matter is in motion it tends to remain for ever in motion One phase of this property is known as inertia of rest and the other inertia of motion We have considered the former and we now proceed to consider the latter

Further Experiments.

1 Make a pile of six draughtsmen Strike horizontally the one next to the bottom of the pile How do the others drop, and why?

2 Stand a disc of cardboard on the neck of a wide-mouthed bottle Having placed a coin on the top of the disc, remove the disc by a smart horizontal stroke Where does the penny fall? What is the cause of this?

3 Place a revolving egg beater in a vessel of water Turn the handle once or twice Which turn of the handle is most difficult to make?

4 Place a button on the back of the hand Turn the hand rapidly Where does the button fall? Why is this?

5 Place a pile of glazed cards on a table, allowing one card near the bottom of the pack to project slightly In what manner should this card be withdrawn so as not to disturb the symmetry of the pack? Why?

9. Why a Tram-Car Keeps to the Lines.

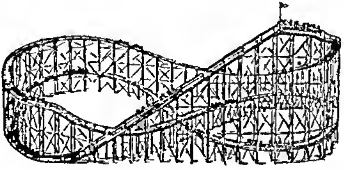
Skim a flat piece of wood along the footpath, just as a girl does when playing hop scotch After moving a short distance it stops and lies quite at rest Now, skim the same piece of wood with the same force along the surface of the ice on a pond Before coming to a stop this time the piece of wood travels a greater distance than it did on the road From this we conclude that the roughness of the surface on which the wood is skimmed has an effect on the distance it travels If we were to make the surface still smoother, the wood would travel farther again Why? Because we should then have made the resistance to its motion still less No one has yet succeeded in getting rid of all resistance, if such a thing were possible we should be able to make a machine which would run for ever without stopping or slowing down

Although perpetual motion has not been made possible, it is found that when once a thing is in motion it continues to move until one or more forces act against it and finally stop it This statement was first made by Isaac Newton, who explained inertia of rest, and he summed up the fact by saying that the inability of an object to stop its own motion was due to inertia of motion.

When a boy tries to dismount for the first time from

a moving tram car he is apt to fall forward on his face, because his body partakes of the motion of the car Even though his feet may bave been brought to rest suddenly, the other parts of his body continue to move for a fraction of a second with the speed of the car This we say is due to inertia of motion, for it is obvious that during this moment of time his body can neither stop nor slow down its own motion We can understand now why the car conductor leans backwards when he steps from the moving car He has learnt by experience that the upper part of his body will be carried by its inertia from its sloping position into a position above his feet and then he can stand upright

We see inertia in operation on the switchback railway (*Picture* 52) After the car has finished running



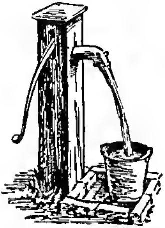
Picture 52

down the incline its motion is continued by its inertia, and this is sufficient to carry it to the top of the next crest. If we roll a small marble down the inside of a basin we see the influence of inertia, for the marble rolls from one side to another several times before

it comes to rest in the bottom of the basin This case is very similar to that of a clock pendulum, the force of gravity causes it to move to the bottom of its swing, but its inertia carries it beyond this point The action of a garden swing (*Picture* 53) a rocking horse, a cradle, or a swing door are further examples of the influence of the inertia of motion Great use is made of this by workmen The blacksmith could not flatten out a lump of red hot iron if he were simply to press it with the head of his hammer, but when he swings his hammer and brings it down smartly on the hot metal the extra energy due to its inertia readily flattens the heated lump The mechanic finds that it is easier to use a hammer if kept in continual motion, and the work man who beds the stone sets in the roadway keeps his "dumper" swinging all the time he is using it The labourer fills his shovel with coals and gives it a swing in the direction he wishes them to go, a sharp jerk stops the shovel, but the coals are shot off to the required place The fireman points the nozzle of the hose pipe in the direction he wishes to send a spray of water, and the inertia of the moving water carries it in this direction after it has left the pipe When water is being drawn from a pump the bucket is not placed just under the delivery spout,

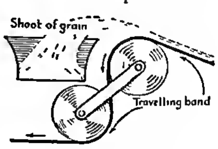
Picture 53

but a little forward (*Picture* 54) at the place to which the inertia will carry the water Dredgers and grain elevators deliver their material by means of inertia of motion (*Picture* 55) Of course the path taken by the material will be modified by gravity



Picture 54

We can make a long list of examples of inertia of motion which are seen at home The sprinkling effect, when a pepper duster or vinegar bottle is used, depends upon this The distances traversed by piano hammers or typewriter arms when compared with the small depression of the keys are further examples We can also include in our list the dropping of ink by a shake of the pen A can of paint is difficult to stir until all the particles in it have been given a whirling motion, when inertia keeps them moving, and the stirring proceeds easily



Picture 55

The inertia of an object in motion is of great advantage to engine constructors The fly wheel of the engine keeps up an even motion between the strokes of the piston This explains, too, why most single

cylinder motor-cycles are fitted with a fly-wheel On the other hand, conveyances are fitted with brakes to overcome this inertia, and so prevent the vehicle from over running itself

A tram car follows the straight track laid down for it and keeps to the lines, because it would need a tremendous force to overcome its inertia and start it on a new path If the direction of the tram car s motion has to be changed, it must be done gradually by a bend in the track which is not too sudden, and the driver must be careful to slow down the car as it takes the bend If we examine a tramway track where such a bend occurs, we can see by the wearing of the metal, that there has been much resistance to the change of direction Why is it that the tram car is more liable to jump the rails at the points than it is on the straight run?

Some years ago in the town of Mossley, near Manchester, a tram car was proceeding down a long steep hill, at the foot of which the track turns sharply to the left over a railway bridge The car began its descent at the normal rate but it quickly gathered speed The driver attempted to check its career by means of the brakes Imagine his dismay when he found his efforts futile The brakes refused to act By its inertia the car followed the track all along the straight length As it approached the bend the driver made a last unsuccessful effort to check its speed At the first deviation from the straight path the car was carried by inertia off the rails and forward in the

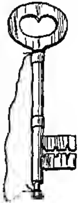
same direction as before It crashed through a stone wall and was wrecked

When we see in the circus an acrobat flying from one trapeze to another we are witnessing a novel application of inertia of motion The gymnast could not take a direct leap from one trapeze to the next, but, by working up a swinging motion on one trapeze he gains enough inertia to carry him through the air safely to the next trapeze

Picture 56

Several toys with which we are familiar depend upon inertia of motion Many toy shops sell the "cap banger" (*Picture* 56), a little toy consisting of two pieces of iron resting together so that a small percussion cap can be placed between them The lower piece is a hemisphere and the upper piece a cone They are bound together loosely by a loop of string, which is left long at one end so that it can be held in the hand Whilst still holding the string a cap is placed between the two pieces of iron and the weighted end is dropped quickly to the floor, and there the bottom part of the cap banger stops The upper part, however, continues to drop for a fraction of a second longer and strikes the cap, which goes off with a loud bang We can improvise a cap banger by placing the head of a match in the barrel of a key and pushing a round nail gently into the barrel

(*Picture* 57) If this is now dropped so that the nail strikes the ground first inertia comes into play, as before, and the match-head fires with a loud report With a pill box, a metal button, and a little sealing-wax, a roller which will roll up a sloping desk can be made Remove the lid of the box, and, with the sealing-wax, fix the metal button on to the side of the box Replace the lid and fasten securely The box will now roll slowly up a sloping surface, if it is given a slight push, because inertia carries the weighted part of the roller into a position from which it can begin another turn



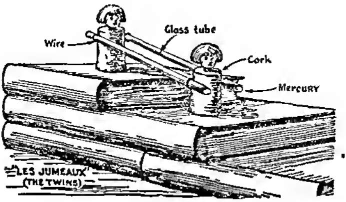
Picture 57

Picture 58

If a fresh egg is spun round rapidly the liquid interior is given a spinning motion If the egg is now touched, for a moment only, by the finger, it stops (*Picture* 58), but as soon as the finger is removed the egg again begins to spin This is because the inertia of the liquid keeps the interior moving, after the shell has been brought to rest, and, if the finger is then removed, the motion of the liquid inside is communicated to the shell to make it spin again Would a hard-boiled egg do the same?

In France, boys and girls often make for themselves a

toy known as "Les Jumeaux"—*the twins*—(*Picture* 59). Two corks, a few inches of thin wire, two narrow glass



Picture 59.

tubes open at both ends, and a little mercury are required. The tops of the corks are decorated to represent dolls, and two pieces of wire are arranged to pass (one through each doll) from shoulder to shoulder. The tubes are first sealed at one end, a drop of mercury is placed in each, and then the other ends of the tubes are sealed up. The tubes attached by the wires join the dolls together and represent their arms. A staircase is made from a pile of books, or boxes of varying heights, and the twins are placed on the top step and pushed until one of them drops on to the next step below. The second twin will now describe a semicircle in the air over the head of the other twin, and land another step down the staircase. The first twin will now do what the second one has just done, and this process continues till the twins

have descended step by step to the bottom of the staircase Care must be taken that too much mercury is not placed in the tubes, for this will resist instead of increase the inertia of the higher twin

Many accidents are caused by inertia When a horse, which has been rapidly moving in a straight line, suddenly stops or shies, what is likely to happen to the rider? *Why?*

Further Experiments.

1 Make a spinning top by pushing a pencil through a disc of cardboard Spin the top on a cloth, on a piece of sand paper and on a piece of glass Where does it spin longest? Explain your results.

2 Arrange a long strip of waxed paper to form a switch back track, using books to support it From a teaspoon pour a few drops of water on the highest crest How do you explain the path taken by the drops?

3 Thread a button on a string and hold one end of the string in each hand Whirl the string three times with one hand and notice how many times the button turns Explain your discovery

4 Arrange a sloping trough from a water tap Turn on the water and note where a cup must be placed to fill it with water What do you conclude?

5 Make a model diving-chute and roll a ball down it. Where does the ball strike the water?

6 Tie a large stone to one end of a thin rope and a small stone to the other end Throw them up in the air How do you explain the path taken by the smaller stone?

10. How a Weighing Machine Works.

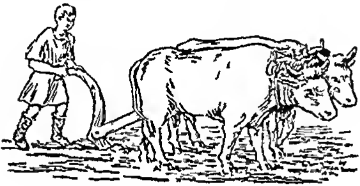
We are all acquainted with many different kinds of machines At home we have a machine to do the *sewing*, an*other to help with the washing, one to* mince the meat and even one to tell us the time When in the street we notice others — motor cars, tram cars cycles cranes, pumps and railway signals

Our workshops and factories are filled with more machines—some for cutting materials, some for joining them together, others for grinding and crushing There is hardly any limit to the variety of the machinery which exists in the world

Why should we have any machines at all? To answer *this question we shall need to decide what* a machine is Let us imagine what the first man who wished to break up the soil would have to do As he had no tools he would be compelled to use his hands — a very tedious business we may be sure. Because of this, he would one day make a very simple machine to help him to do this work He would cut down a branch of a tree, burn it to a point, push the pointed end into the ground, and, by pressing the other end, would force a lump of earth out of place We are not certain what actually happened but we do know that the Romans used to plough their fields by using a pointed stick as their ploughing machine (*Picture* 60) A very primitive sort of machine we think it to day, but still it was

a machine, because it was an arrangement by which a force exerted at one point was changed into a force acting at a different point

The machine made by the first digger was of a

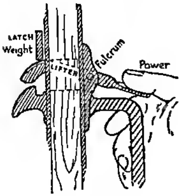


Picture 60

very simple character, and is now known as the **Lever** Its essential features were rigidity and a special point which did not move whilst the machine was working When the stick was forced into the ground, this special point, the **fulcrum** as it is called, was at the surface of the soil From this point the stick extended in two directions, each portion acting as an **arm** of the lever When the digger pressed *downwards* at his end of one arm, the lever transformed his power in such a way that the other arm displaced the earth *upwards* and the fulcrum remained at rest

Thousands of levers are in use in the world, but all of them have the same essential features They

are all rigid, though not of necessity straight, and all have a fixed point (the **fulcrum**) about which they turn Where is the fulcrum of a railway signal, of a turnstile, and of a trap door?



Picture 61

We have seen that in using a lever a force applied at one point is made to act at a different point Consider another example When using a door-latch (*Picture* 61) we apply a force by pressing the thumb downwards on one end of the rigid arm, and as a result the other arm moves upwards and so raises the bar of the latch out of its socket To prevent confusion when speaking of these two forces, it is usual to name the force *applied* as the **power**, and the force *overcome* as the **weight or resistance**


Picture 62.

The scales used in a grocer's shop illustrate this very clearly (*Picture* 62) When the grocer wishes to serve a pound of tea he places on one side of the scales a pound-weight—that is, a piece of metal which the earth pulls down with a force of one pound The pound-weight is the resistance, and

the power is the earth's pull on the tea which is placed on the opposite side of the scales The grocer is said to have weighed a pound of tea when the power and the resistance are equal Is there any reason why the arms of the scales are equal in length? Does it matter on which side of the scales the weight and power act? What happens if too much tea is placed on one side of the scales? These are questions to which we must supply answers.

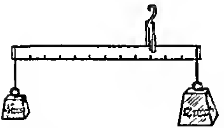
Let us consider the influence of the length of the arms on the accuracy of the scales Make a pair of scales by hanging the lids of coffee tins from each end of a ruler Bore two holes in the ruler, one half way between the ends and the other one nearer to one end than the other Hang the ruler from the hole at its mid point and in each of the lids place six marbles of equal weight The rod balances Hang it from the other hole Does it balance? We can see at once that it is unbalanced This gives us some idea why the grocer's scales are hung from the mid point of the beam The fulcrum must be half-way between the power and the weight if the beam is to balance when they are equal Such a pair of scales is said to be accurate

Adjust the improvised scales so that they are again accurate Change the marbles from one lid to the other Does the beam still balance? We cannot detect any difference, for the scales are still accurate This leads us to conclude that when using a lever with arms of equal length it does not matter whether

the power acts at one end or at the other, nor does it matter at which end the weight acts The grocer may place his tea in either of the pans of his scales, and if it counterbalances the metal weight in the other pan he knows that he is serving a definite amount of tea to his customer

If we add an extra marble to one side of our balanced scales we see the balance is immediately destroyed, for the beam swings over to the side of the greater load We have made the power greater than the weight, and under this condition it is impossible to balance the scales at the mid-point of the beam When the grocer adds too much tea to one side of his scales he also is making the power greater than the weight, and if he is content with this his customer will gain an advantage

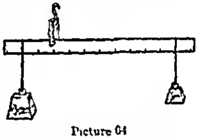
Would it be possible to arrange a lever to balance if its arms were unequal? We can easily test this for ourselves Select a uniform twelve inch ruler and hang it from a point three inches from one end At this end hang twelve ounces of metal At the other end hang



Picture 63

weights until the rod balances Examine the weight used and also measure its distance from the fulcrum Allowing for the slight extra weight of the long arm of the lever itself, we observe from this experiment

that a twelve-ounce weight acting three inches from the fulcrum counterbalances a four-ounce weight acting nine inches from the fulcrum We know that $12 \times 3 = 4 \times 9$ Does this relation between (i) the power and its distance from the fulcrum, and (ii) the weight and its distance from the fulcrum always hold good? Let us experiment again This time arrange a weight of four ounces two inches from the fulcrum and find the position on the other side of the fulcrum where a one-ounce weight will balance it We find that the one ounce weight must be placed 8 inches from the fulcrum Notice that $4 \times 2 = 1 \times 8$ We could perform a large number of experiments of the same type, and we should



Picture 64

find that when the lever is balanced the product obtained by multiplying the magnitude of the power by the distance of the point where it acts from the fulcrum always equals the product of the weight and the distance of its point of action from the fulcrum (*Pictures* 63 *and* 64) Thus when the power is 5 lbs and it acts a foot away from the fulcrum, what weight, acting 5 feet from the fulcrum, will just balance it? Having worked out this problem test your solution

We call the product of the power and its distance from the fulcrum the **turning moment of the power.** Similarly, the product of the weight and its distance from the fulcrum is the **turning moment of the weight.**

the power acts at one end or at the other, nor does it matter at which end the weight acts The grocer may place his tea in either of the pans of his scales, and if it counterbalances the metal weight in the other pan he knows that be is serving a definite amount of tea to his customer

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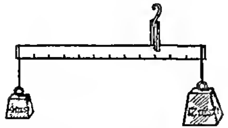
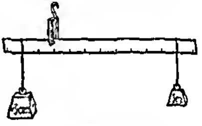
Would it be possible to arrange a lever to balance if its arms were unequal? We can easily test this for ourselves Select a uniform twelve inch ruler and hang it from a point three inches from one end At this end hang twelve ounces of metal At the other end hang weights until the rod balances Examine the weight used and also measure its distance from the fulcrum Allowing for the slight extra weight of the long arm of the lever itself, we observe from this experiment



Picture 63

that a twelve-ounce weight acting three inches from the fulcrum counterbalances a four-ounce weight acting nine inches from the fulcrum We know that $12 \times 3 = 4 \times 9$ Does this relation between (i) the power and its distance from the fulcrum, and (ii) the weight and its distance from the fulcrum always hold good? Let us experiment again This time arrange a weight of four ounces two inches from the fulcrum and find the position on the other side of the fulcrum where a one-ounce weight will balance it We find that the one-ounce weight must be placed 8 inches from the fulcrum Notice that $4 \times 2 = 1 \times 8$ We could perform a large number of experiments of the same type, and we should find that when the lever is balanced the product obtained by multiplying the magnitude of the power by the distance of the point where it acts from the fulcrum always equals the product of the weight and the distance of its point of action from the fulcrum (*Pictures 63 and 64*) Thus, when the power is 5 lbs and it acts a foot away from the fulcrum, what weight, acting 5 feet from the fulcrum, will just balance it? Having worked out this problem test your solution



Picture 64

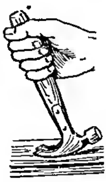
We call the product of the power and its distance *from the fulcrum the turning* **moment of the power.** Similarly, the product of the weight and its distance from the fulcrum **is the turning moment of the weight.**

In the case of scales which balance, the turning moments of both are alike, hence when the arms are not equal either the shopkeeper or the customer loses What decides who loses and who gains? We can now see why a balancing position can be obtained with scales having unequal arms if the weight and power can be so adjusted that the two turning moments are equal

Picture 65

The advantage gained in using a machine is known as **mechanical advantage**

There are hundreds of ways in which levers are employed to gain mechanical advantage The workman uses a long armed crowbar (*Picture* 65) the stoker a long poker, the navvy a long shaft to his pick and shovel, because it is then possible to apply the power a good distance from the fulcrum, and thus increase the turning moment on one side of the fulcrum We know by experience that it is much easier to pull out nails if we use a long pair of pincers, or a claw hammer with a long shaft (*Picture* 66) Also, in pumping, advantage is gained by having



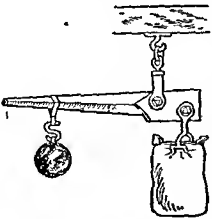
Picture 66

a long handle to a pump Nut-crackers, hinged lemon-squeezers, long chisels, and broad handled screw drivers are all machines used to gain mechanical advantage

A boy and a girl may be unequal in weight and yet on a see saw the lighter boy can raise the heavier girl by virtue of their respective positions on the plank (*Picture* 67) Where must the boy sit? Obviously he must be farther from the balancing point than the girl so as to

Picture 67

make his turning moment equal to hers Should a second boy mount on the see saw what are the possible effects of his power? How may the effect be varied? On a see saw it is seen that mechanical advantage is gained when a small force overcomes a larger force What may we notice about the distances the children rise when the see saw sways? Is there any relation

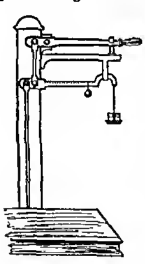


Picture 68

between their weights and the distances they travel?

Interesting applications of these principles are seen when we consider the action of a weighing machine

The Romans made use of a lever when they weighed the tribute corn from their provinces (*Picture* 68) This machine has still kept the name of the Roman steelyard, and it is so arranged that a very small weight can be used to balance a much greater one From this we know that the steelyard must have unequal arms The greater weight is hung from a fixed point very near to the fulcrum, and, on the opposite side of the fulcrum, a smaller weight is hung This small weight is moved about on the long arm until a position is found where it is able to balance the greater weight. The long arm of the lever is graduated like a rule, so that, by observing the distance of the smaller weight from the fulcrum, the exact weight of the object hung on the short arm can be calculated • The value of this steelyard depends on the accuracy of the scale



Picture 69

Most weighing machines work on the same principle as the Roman steelyard We may see them in use in the butcher's shop when large carcases of meat are being weighed

In wharves where trucks of coal are weighed a weighbridge is used It would be very inconvenient when weighing very heavy loads to

be obliged to use scales needing weights such as a ton or a hundredweight and so a system of levers is arranged The truck is run by means of rails on to a platform This platform is connected by a strong con necting rod to the short arm of a lever (*Picture 69*) The lever has a knife edge fulcrum and the other arm is extended and graduated to scale At the end of this long arm is a scale pan Because of the difference in length of the arms a small piece of iron on the scale pan will counterbalance a ton weight resting on the platform A calculation is made to determine the amounts of iron which at the distance of the long arm will counterbalance a ton a hundredweight and a quarter placed separately on the platform and then weights are made to correspond to these loads To weigh the truck when it is on the platform the nominal weights which correspond to the larger ones are placed on the scale pan The number of tons hundredweights and quarters is first determined and the remaining pounds more than this are then ascertained by sliding a small steel runner (shaped like a large ear ring) over the graduated arm When the long arm is horizontal the weight of the truck is easily obtained correct to the nearest half pound It is usual to detach the connecting rod from the short arm of the lever when the machine is not in use so that the knife edge fulcrum is not damaged by the continued weight of the platform To do this a handle is provided When the handle is pressed down the connecting rod engages with the short arm of the lever and the weighing can proceed

where the power acts and the other where the weight acts In the case of the wheelbarrow (*Picture 71*) the fulcrum is the axle of the wheel The weight is in the barrow and the power is applied at the handles Why should a barrow be easier to handle if the load is placed as far forward as possible? A pair of nut-crackers is another example of the same arrangement

A still stranger arrangement is seen in the working of the treadle of a grindstone (*Picture 72*) How does it differ from the treadle of a sewing-machine? When

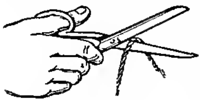

Picture 72.

Picture 73

we raise a weight in the hand, the bones of the fore-arm form a lever having the fulcrum at the elbow (*Picture 73*) This is in the same class of lever as the grindstone treadle, spring shears, and sugar tongs

Levers have often been combined to produce more intricate machines—as in the common scissors (*Picture*

74) and the hand-brake on a cycle The arms of the lever may be bent or curved, as in a pair of pliers or the valves of a piccolo But, however intricate a machine may be, it will always be found to have some parts which are levers in principle



Picture 74

Picture 75 will interest you.

Further Experiments.

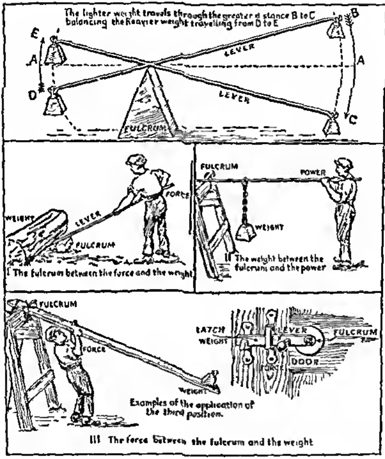
1 Stretch the arm sideways as far as possible, holding a half pound weight on the palm of the hand Attempt to raise the weight without bending the arm Now repeat the attempt, bending the arm at the elbow Explain the difference

2 Using a light uniform piece of lath, three hair pins, and a heavy button, make a letter balance on the principle of the Roman steelyard

3 Given a uniform broomstick, a half pound weight, and some string, find the weight of a stone

4 A 10 lb weight is tied to one end of a walking stick which rests on one shoulder Find the most comfortable position for holding the stick and explain why it is so

5 Given a crowbar and a 56 lb weight, in how many ways can you use the bar to displace the weight?



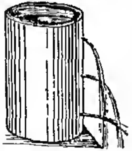
The lighter weight travels through the greater distance B to C balancing the heavier weight travelling from D to E
E
A
D
B
A
C
LEVER
LEVER
FULCRUM
WEIGHT
LEVER
FORCE
FULCRUM
I The fulcrum between the force and the weight
FULCRUM
POWER
WEIGHT
II The weight between the fulcrum and the power
FULCRUM
FORCE
WEIGHT
LATCH
WEIGHT
LEVER
FULCRUM
DOOR
FORCE
Examples of the application of the third position.
III The force between the fulcrum and the weight

Picture 75.

11. Why Things Float.

We know by experience that if we wish to keep a cork at the bottom of a tumbler filled with water we must press the cork down, say with a finger or a rod We also know that as soon as the pressure is removed the cork will rise to the surface Now we have learned that a thing will not move unless it is made to do so by a force, and it will be interesting to find out what force makes the cork rise to the surface of the water We can be quite certain that whatever force causes the cork to move it must be a force greater than that of gravity, because the tendency to fall is overcome and the cork is caused to move *upwards*

Obtain a tall, water-tight tin vessel and puncture the side of it, making three holes at varying heights (*Picture* 76) We can fill the vessel with water by keeping our fingers over the holes, but as soon as we remove our fingers, out comes the water in three jets The water is being forced out, and this time the force is acting *sideways* It will be noticed that the water is forced out from each of the holes to a different distance The longest jet is coming from the lowest hole, and the shortest jet from the topmost one This suggests that the force varies in intensity according to the place where it is exercised, being greatest at the lowest point and least at the highest point.



Picture 76

From the two foregoing experiments it is clear that this force acts both upwards and sideways. Does it act in any other direction? Yes there is a *downward* force as well, due to the weight of the liquid. What is this force which is acting in every direction? We speak of it as liquid pressure.

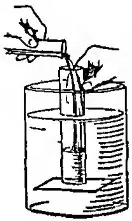
Let us perform another experiment. Draw into a fountain pen filler, or into a syringe, a quantity of olive-oil. Then dip the pointed end of the tube under the surface of clear water in a glass tumbler, and gently squeeze out a drop of the oil (*Picture 77*). *Notice the shape of this drop as it rises to the surface.* It is nearly spherical, and from this we conclude that it is under the influence of almost equal forces all round it. All experiments with liquids help to prove that below the surface of any liquid there are forces acting in every direction.

Picture 77

We have now observed three very important facts about liquid pressure, namely, (i) within a liquid there are forces acting in every direction—downwards, upwards and sideways, (ii) at any point within the liquid these forces are equal, (iii) as the depth of the liquid increases there is a corresponding increase of pressure. Scientists express this last fact by saying that the pressure of a liquid varies with the **head of liquid**.

We may illustrate this statement thus: Place a

postcard flat on the surface of water and push it under the water by means of a lamp glass held vertically (*Picture 78*) The card covers the end of the lamp glass and remains there because the water presses it upwards As the card is pushed lower this pressure becomes greater, and at a depth of about a foot, the force of a pea shot down the lamp glass from a pea shooter, does not disturb the card Now pour water into the lamp glass This does not have any obvious effect on the card until the water reaches the same height inside the lamp glass as it is outside When this stage is reached the card falls by its own weight because we have then imposed a pressure which is exactly equal to the pressure which is acting upwards. This is true because both sides of the card are very nearly at the same depth or in other words, they are under the same head of liquid


Picture 78

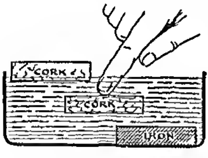
The effect of head of liquid is seen in everyday life To obtain the maximum pressure in the water supply of a town the reservoir is placed well above the town on the highest land available The supply tank for a fountain is placed as high as possible, so that the water from the exit tube of the fountain will be forced to a great height The water carts on the streets send out a much longer spray when the tank

is full than when it is almost empty A plug to stop a leak in a water butt is driven from the inside Sediment in a deep lake or canal is pressed by the water above it till in a few years it is almost as hard as sandstone The water pressure in the ocean is very great indeed—as much as one ton per square inch at a depth of a thousand fathoms Because of this great pressure a diver's body has to be protected with a suit which is inflated with air just as we inflate a football or a bicycle tyre, and his head is protected with a brass helmet (*Picture 79*) In order to make him sink into the water he wears boots, weighing twenty pounds each, and heavy weights of lead are attached to his breast and back The total weight of a diver's suit is over 150 pounds For many years it was considered very unsafe to work in places deeper than 200 feet below the surface of the ocean, in fact, the ordinary working limit was about 150 feet. In November, 1925, a British submarine was lost off Start Point, Devonshire, and attempts were made to salvage it With certain apparatus divers reached a depth of 500 feet, but since then a descent of about 650 feet has been made Because the water pressure makes him very buoyant, the diver has little pushing or depressing power For this reason, therefore, he cannot use ordinary tools unless he can create sufficient resistance by resting his back against some

Picture 79

firm object like a rock To overcome this difficulty he uses pneumatic tools which require little exertion on his part to keep them to their work, but which are heavy enough to form their own resistance to the strokes they make

Now we come to a very important and rather difficult part of this subject. We must keep clearly in our minds that when an object is under the surface of water it is pressed by the water *in all directions*, but not equally—the pressure varies according to the depth Thus in the case of the cork in water the lower surface is pressed upwards more than the upper surface is pressed downwards When the cork is immersed in water it takes up the space previously occupied by an equal volume of water (*Picture* 80)



Picture 80

This water was at rest—it moved neither up nor down its weight was supported by the *upthrust* The same amount of upthrust is now acting on the cork, but the weight of the cork is less than the weight of the same volume of water Consequently the cork is pushed up If iron occupied the space where the cork is the upthrust would still be the same namely the weight of the water which was there before the iron took its place But the weight of the iron is greater than this weight of water

Consequently the iron falls Is it not clear then why some things sink and others float? And a very important point to note is, that the weight of the water displaced by an object is equal to the up thrust of the water on that object

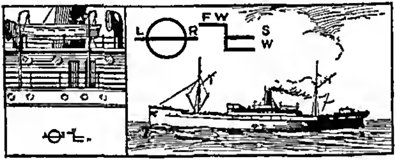
The first person to discover this truth was a philosopher named Archimedes, who showed that the upthrust on a submerged body makes the weight of the body appear to be less than it really is This loss in weight must, of course, equal the upthrust, and must therefore be equal to the weight of liquid the object displaces Ever since this wonderful discovery was made it has been known as the Principle of Archimedes

This apparent loss in weight is due to the upthrust of the liquid acting upwards against the force of gravity, which acts downwards on the object When the upthrust is the greater of these two forces the object rises to the surface of the liquid and we say it floats • This is what happens with the cork in water, but when a piece of iron is in water the force of gravity is not overcome by the upthrust and con sequently the iron sinks

There is an upthrust on every submerged object This explains why a boy, learning to swim, is easily supported in the water by a very little pressure applied under his chin For the same reason a heavy piece of masonry can be moved, when under water, by a crane which could not raise it in air

We may ask why a ship, constructed of iron plates, floats in water, although iron itself sinks in water

This is because the ship is so built that it displaces an amount of water which is much greater than the bulk of actual *iron* This displaced water causes enough upthrust to float the whole By loading the ship, its weight may be increased until the downward force of gravity is nearly equal to the upthrust, and yet the ship will float Each addition to the weight of the ship submerges it more and more To prevent accidents due to overloading of ships all British vessels are compelled to carry a mark, known as the Plimsoll Line (*Picture* 81) on their port side This

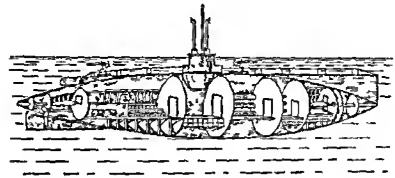


Picture 81 L R – Lloyd s Register F W = Fresh Water S = Summer, W = Winter

mark shows to what depth the ship may be safely loaded In the same way the weight of a submarine, when it is to be submerged, is made greater than the upthrust on it by water being taken into its tanks (*Picture* 82) The reverse process of pumping water out of its tanks causes it to rise again to the surface

It must not be supposed that the same object is always subject to the same upthrust—this varies with the different kinds of liquid in which the object

is immersed Thus the upthrust in sea water is greater than in fresh water, and so ships are often loaded deeper whilst in river water, viz to a point (see F W, *Picture* 81) above the Plimsoll Line, but on reaching the sea the captain must observe regulations The upthrust in a liquid like mercury is very great indeed—nearly fourteen times as great as it is in water A

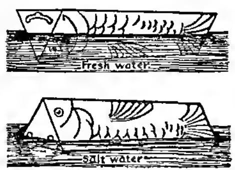


Picture 82

solid block of iron will float on mercury Every swimmer knows that it is easier to float in salt water than in fresh water A fresh egg sinks when placed in pure water, but floats on the surface in strong brine "Bathers who venture into the Dead Sea find it impossible to sink below the surface, and suffer from irritation of the skin after immersion owing to the extreme saltiness"

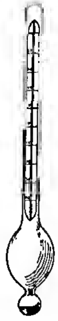
An interesting toy can be made to show this difference of upthrust Take a triangular prism of light wood without knots in it, about 2 inches long

and 1 inch wide With a penknife carve one end of it to represent the head of a fish (*Picture* 83) Paint scales on it and it will look quite realistic Now place the fish in a shallow basin of fresh water It will at once turn over on its back like a dead fish but if salt is added to the water, it will turn over again and float with its edge upwards like a live fish Why is this?



Picture 83

Many uses are made of the difference in upthrust between one liquid and another The milk inspector uses this principle as a means of testing the quality of milk A glass tube is loaded with mercury (*Picture* 84) and on the tube a scale is marked This tube floats in the milk to a depth which varies with the amount of fat in the milk We can make such an instrument for ourselves by weighting a black lead pencil to make it float upright in water, and marking with a penknife the depth to which *it is* immersed Put the pencil in a jar of milk and we find the mark is above the milk surface Using our weighted pencil in other liquids we find that the depth submerged varies


Picture 84

with the liquid This is the basis of the testing instrument used by manufacturers of oils and of acids to test the strength of their liquids Brewers, publicans, and excise officers also use a similar instrument to test whether their spirits are up to the standard which the law demands

Further Experiments.

1 Hold a hollow, rubber ball under the surface of water in a tank Explain what happens when it is released Do the same with a ball of iron and say how you would account for any differences observed

2 Float a tumbler in water Why does it float? Pour water into the tumbler till it sinks How much water must be added?

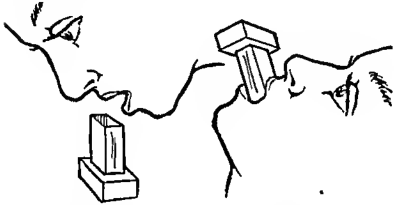
3 Place a large sponge on the surface of water in a basin Leave it for a few minutes Explain all the changes which occur

4 Weigh a paving stone on a spring balance Now lower the stone into a tank of water and again notice the weight What has occurred? Would the stone weigh the same if it were lowered into the sea?

5 Float a ruler upright in water Notice how far it is submerged Notice the depth to which it is submerged when placed in methylated spirit What would you expect to be its depth in a 50% mixture of spirit and water? Test this conclusion

12 Why the Wind Blows.

Obtain an empty match box with its cover and try this experiment Stand the empty box on the table in an inverted position and on the top of it place the cover in an upright position (*Picture* 85) The problem is to re arrange the box and its cover so that the box is then supported on the top of the cover like a pedestal—that is the whole is to be turned right

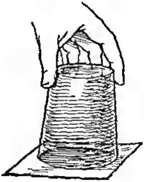


Picture 85 Picture 86

over so that the box is on the top, and yet the *box* is not to be touched by the fingers Proceed thus Place the mouth to the open end of the cover, draw in a deep breath through the mouth as though sucking air out of the cover, and quickly throw the head well back whilst still drawing in the breath (*Picture* 86) It will be seen that the two parts of the match box hold together, and that both are in the position desired Now take the cover carefully between the finger and

thumb, and both it and the box may be placed on the table with the upturned box supported on the upright cover What is the explanation of this? Let us see. It is evident that when the box rises in the air something is causing it to be pressed against the cover But we cannot see what is causing this Perhaps it is the air pressing on the open surface of the box Much of the air within the cover is sucked out before the head is thrown back, and this causes a greater pressure of air on the open surface of the box than on the other side Let us try to make sure that it is the air which is pressing upwards

Here is another experiment Fill a tumbler with water to the brim and cover the water with a post card Holding the postcard in position with a finger, quickly turn the tumbler upside down (*Picture 87*) What did you expect? Did you not expect the water and the postcard to fall to the ground? But the postcard remains in position Why? The air, by exerting pressure on the postcard, is preventing the water from running out The air is pressing *upwards* with a greater force than that exerted by the water, which tends to fall to the ground Yes, air exerts a pressure upwards

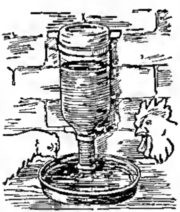


Picture 87

And, like all other things on the earth, it exerts a pressure *downwards* on account of gravity Does it

his opinion of this new scent We shall rarely hear this opinion, for no sooner has our friend removed the stopper than he feels an inconvenient trickle of water down his sleeve and amidst the fun his opinion of the odour of the 'scent' is forgotten This device depends upon the air pressure on the small hole being sufficient to overcome the weight of the water, so long as the stopper prevents air pressure from above It is for the same reason that a vinegar barrel has to be provided with a vent hole as well as a hole for the spigot

Many useful devices can be constructed by utilising air pressure A simple drinking trough can be made to give a constant supply of pure water for poultry by closing the neck of a bottle full of water, inverting and re opening it under the surface of other water contained in a shallow dish (*Picture* 89) Although



Picture 89

the bottle is upside down the water in it does not escape, for the air pressure on the surface of the water in the dish is supporting the water in the inverted bottle The bottle remains full of water so long as the surface of the water in the dish does not fall below the mouth of the bottle But when the water in the dish has been drunk by the fowls, or evaporated, or when the surface of this water is lowered by any othe at once

the water in the bottle flows out until the mouth is again covered The air pressure on the water in the dish once again supports the water left in the bottle This process may be repeated so long as there is any water remaining in the bottle. It is interesting to experiment in this way with ordinary bottles of varying capacities In all such cases it is found that the air supports the weight of the water in the bottle

Now what is the length of the highest column of water which the air will support? Is there a column of water so high that the air will not support it? Many years ago the citizens of Rouen were surprised one morning to see in their market place a great tube over thirty feet in height standing inverted in a pail of water The answers to our two questions were being sought for It was found that the highest column of water which the air would support was about thirty two feet and that whatever height of tube was used the air would not support the weight of a column of water any higher Think what the water in a tube forty feet high would do when inverted The water would of course sink to a height of thirty two feet

We now understand why water cannot be raised by an ordinary pump from a well more than thirty two feet in depth Before this experiment was done in Rouen experiments of the same type were made in Florence with other liquids and it was found that the height of the liquid column varied very much indeed When using a very heavy liquid such as mercury, the column stood at a height of about thirty inches It

was soon found also that the same kind of liquid, when tried in different places at the same time, gave different results This suggested that the air pressure might not be the same at all times nor the same at all places We can prove this to be true by the following arrangement First, let us fill a jar with water right to the brim, and then tie over it a thin india rubber sheet in the way in which a jam jar is covered with gummed paper Now let us hang our jar in an inverted position from a hook fixed out of doors The india rubber bulges outwards, of course, but if we watch it day after day we find that the amount of this bulge varies Why? The air pressure varies Is it possible to measure these varying pressures? Yes, and this is generally and most conveniently done by using the mercury column But, whatever liquid we use (and whether we use a liquid or not), an instrument for measuring the weight or pressure of the atmosphere is called a barometer

As a rule, air pressure is greater at the seaside than at the top of a mountain We can confirm this for ourselves by consulting the morning newspapers There we may find a record of the barometer readings at different places, some of these places are situated at the seaside and some inland

This difference of pressure at various places exercises a great influence on our lives Imagine what occurs when air is at high pressure in one place and at low pressure in an adjoining place Here is an interesting experiment which may assist our imagination

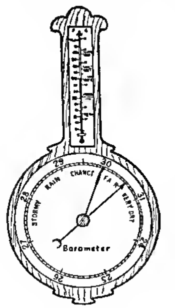
Obtain a glass water-bottle, about eight inches in height and having a neck about an inch wide (*Picture* 90). Now prepare a banana by peeling it one quarter of its length. Then pour into the bottle a layer of methylated spirit, and fire it by dropping on it a lighted match. This causes the air within the bottle to become warm and to expand. The expanded air at once searches for a means of escape from the bottle, and after a minute there is very little air remaining behind. A region of low pressure has thus been made in the interior of the bottle. At

Picture 90

this stage push the peeled part of the banana into the bottle neck and watch what happens. The banana is slowly forced right into the bottle by the pressure of the outside air, and as it enters the skin is peeled off. When the last portion of the banana has passed into the bottle a sharp pop is heard due to the outside air rushing in to fill the bottle completely.

We can see, therefore, that air tends to move from a place where the pressure is high towards a place where the pressure is low. If we think about the experiment again we see that difference in air pressure is largely due to difference of temperature. When air is heated it expands, it becomes warmer, and it rises, and this causes a lowering of the pressure at that spot, and there follows an indraught. We see this principle exemplified when smoke is rising in a

chimney Whilst sitting in front of a good fire in the grate we often feel that our backs are cold, and we say that the room is draughty What is a draught? It is air moving from a cold place, where the air is at high pressure, towards a place where the air is warmer and consequently at a lower pressure This process is going on when we are sitting before our good fire It is also going on out of doors all the year round, for air is always moving in currents over the surface of the earth We call the currents winds, and give them names, such as the East Wind or the West Wind, according to the direction from which they blow The speed of the wind largely depends upon the amount of the difference in the air pressure at two places It also depends upon the distance the places are apart As these conditions may vary, we have light breezes, fresh breezes, gales, hurricanes, or monsoons blowing over land and sea



Picture 91

We have seen that the barometer is an instrument which records the variations of air pressure, and therefore it is able to tell us the kind of winds we are likely to experience When the barometer *falls* the winds may be expected to blow

towards our region, whilst a *high* barometer indicates out-going winds If the barometer is jumpy we may expect rapid changes in the wind and unsettled weather. This is why the farmer, the aviator, the tourist, and others watch the barometer very closely, for it helps to guide them as to the kind of weather to be anticipated (*Picture* 91)

Further Experiments.

1 Obtain a piece of clean metal, having the shape of a sixpence, and press it to the forehead just above the bridge of the nose Try to remove it by shaking the head What is the result?

2 Place water in a glass tube shaped like a letter U Note the height of the liquid in each limb Why does the level alter if you blow down one limb?

3 Damp a boy's sucker and press it against a smooth wall Attach the string of the sucker to a spring balance Pull the sucker by pulling the ring of the spring balance Notice the reading of the spring balance when the sucker leaves the wall How may this observation be explained?

4 Puncture the lid and the base of a coffee tin by means of a needle Stick a piece of paper over the hole in the lid Close the hole at the bottom with a finger, fill the tin vessel with water, press on the lid, and remove the finger Does water leave the vessel? What happens if the paper over the lid is broken through? What does this indicate?

5 Take a short glass tube, open at both ends, and dip one end in a jar of water Now press the finger over the other end and withdraw the tube. What do you notice when you examine the tube? What happens if the finger is removed from the end?

6 Press down the handle of a garden syringe and place the nozzle under water Draw up the handle What happens to the water, and why?

13. Why Rivets Are Used Red-Hot.

Watch a plumber fixing a glass globe to the gas fittings in a room After he has arranged the glass globe in the socket he adjusts the screws so that the globe can be turned round quite freely Experience has taught him that if he leaves the globe screwed up tightly in the socket the globe will crack shortly after the gas is lit Examination of a globe which has cracked in this way shows that the cracking begins just where the screws touched the glass The exact reason for this is The glass, when warmed by the beat of the gas, becomes larger in every direction, and, if tightly fixed in its socket, this expansion causes a strain which the glass is not tenacious enough to withstand, and consequently the glass breaks at the point of greatest resistance

We all know that glass globes, glass tumblers, glass windows are brittle, even when cold •But they are more likely to break when heated Let us try to find the reason for this It is easy to understand that we are not always able to heat equally and at the same time all the particles of which these glass objects are composed As soon as one portion is heated it expands at once, it does not wait for the next to become warm and to expand The result is that the danger of breaking is much increased, for as the tenacity of glass is not great, it is likely that the heated portion will break away from the next portion which is cooler A similar danger arises

when hot glass is cooling If one portion cools more quickly than that next to it, the glass cracks, for the cool portion begins to occupy less space and breaks away from the next—again because of the low tenacity of glass

Glass is of great use to us because it is solid and transparent Its special property is transparency Light passes through it, and so we are able to see through it But it is also very brittle Men have therefore tried to find a substitute for it They have tried to find a substance which must be transparent, solid, light in weight, and tenacious—and they have nearly succeeded Mica and silica are now sometimes used for the windows of oil stoves, bicycle-lamps, and for other purposes where sudden changes of temperature are likely to occur Gas globes made from silica can now be purchased in some of our shops So little do these silica globes alter in size when heated that they can be made red hot, and whilst in this state they may be plunged into cold water without cracking them Substances like silica are however exceptional and in using most of our materials care must be taken, on account of the expansion which occurs when they are heated and the contraction when suddenly cooled

Let us consider some examples in our homes Every girl knows what is likely to happen if very hot water is poured into a fine china vessel It cracks, even if it does not break And the same thing often happens when hot earthenware ve

are plunged into cold water The reason for the damage is similar in both cases One portion of the vessel has suddenly broken away from the next portion because the unequal expansion or contraction has strained it to breaking-point For the same reason the glass chimney of an oil-lamp may crack when a draught of cold air strikes it, and thick glass windows are sometimes fractured during frosty weather

The fire-bars in the kitchen grate are quite loose in their sockets before the fire is lit in the morning, but after they have been warmed by the heat of the fire they no longer rattle, but fit tightly The heater of a box-iron used for ironing clothes fits very loosely indeed in its case when cold, but when it has been made red-hot it fits quite tightly

When we stay up very late at night, until the house is quiet and the fire is dying down, we can hear very faint cracking sounds, mere whispers in fact These are caused by the furniture contracting as it cools, and when shrinking it gives rise to cracking sounds We shall know in future that these sounds are not made by ghosts!

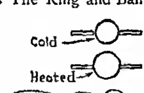
Sticks of roll-sulphur, sold as brimstone, show expansion in a peculiar manner when they are heated When a stick of this substance is held close to the ear, we perceive a noise like the explosion of hundreds of miniature fireworks The explanation is that the thousands of crystals composing the sulphur are expanded by the heat of the hand, and are forced to

push past each other to allow this expansion to take place

Because of the expansion of iron when heated a blacksmith, who must form a horse shoe whilst it is hot, makes it larger than it is actually required for the horse's hoof When cooled it contracts and is then found to fit exactly

A soldier who has fired a hundred rounds of shot in quick succession from his rifle finds the barrel of his gun so expanded by the heat that it cannot grip the bullets but becomes "jammed" until it has had time to cool and to contract to its normal size again

The expansion and contraction of a solid body caused by changes of temperature have been shown very clearly by a French scientist called **Gravesande** He used an apparatus known as The Ring and Ball



Picture 92

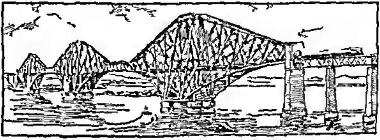
We can perform very similar experiments by using a steel ball and a metal washer through which the ball will just pass Using two pairs of pincers, hold the washer with one pair of pincers in the right hand and hold the ball with the second pair in the left hand (*Picture* 92) (A cloth will be advisable when holding the second pair of pincers) Heat the ball to redness over a gas jet and then place it on the washer We observed the ball pass through the washer when both were cold, and now

when the ball is heated it will not pass through. What has happened? The volume of the ball has increased —it has expanded in every direction, and has now a diameter greater than that of the hole of the washer. Now allow the ball to remain for a little while supported by the washer. Soon the ball passes through the hole. (Take care that the hot ball does not fall on to any material it may damage. A saucer filled with sand makes a good receptacle.) Why does the ball pass through the hole after a little delay? The washer has become hot by contact with the hot ball, and has itself now expanded sufficiently to allow the ball to pass through it, whilst the ball itself has slightly contracted on cooling.

Gravesande's experiments show very clearly that iron expands in every direction. Suppose a very long metal wire were heated, would that also expand in every direction? Yes, the volume of it would increase, the area of its cross section would become greater, and its length would increase also. Which of the increases would be the most obvious? We should more readily notice the increase in length. The variation of the length of an object when it is heated is spoken of as **linear expansion**. A familiar instance of this is seen when telegraph wires bend or sag in hot weather.

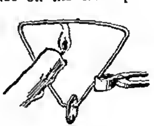
Linear expansion is very important to many kinds of workmen. The man who lays railway lines must leave spaces between the rails to allow them to increase in length on a hot day. The builder must

not cement round the ends of hot water pipes fixed in a building The engineer who constructs a metal bridge must not bed the ends of the main beams in concrete but must rest them on rollers The Forth Bridge (*Picture* 93) the total length of which is nearly



Picture 93

8300 feet has room to slide $1\frac{1}{2}$ feet on its rollers The piano tuner must not tune a piano whilst a room is very hot if he wishes it to have a good tone when the room is cool The pitch of the note changes with the alteration of the length of the piano wire The inspector of weights and measures must remember the effect of temperature on metal yard sticks, and when testing them he must correct his results The clockmaker must include a device on his clock pendulum so that the alteration of the length due to variations of temperature may be compensated



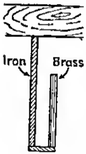
Picture 94

We can construct a simple apparatus to show clearly that a solid when heated expands linearly Bend a hair pin into the shape of a triangle,

open at the apex (*Picture* 94) Now grip a copper coin between the free ends of the wire Hold the triangle with a pair of pincers, as shown in the picture, and warm the mid point of the wire a very little The length of the heated side increases, the jaws open, and the coin falls

The amount of the increase in length caused by a fixed rise in temperature varies for different metals A copper bar increases from 100,000 cms (approx $\frac{5}{8}$ of a mile) to 100 002 cms when its temperature is raised 1° C, but a similar bar of lead heated to the same extent increases from 100,000 cms to 100,003 cms

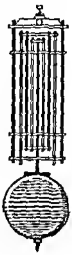
When similar and equal lengths of brass and iron are raised through the same temperature it is found that brass expands about $1\frac{1}{2}$ times as much as iron It follows that, if we obtain two bars, one of iron and one of brass, having the same area in cross section but the iron bar $1\frac{1}{2}$ times the length of the brass one, the actual increase in the length of these two bars will be just the same When they are joined together by a cross bar, and the upper end of the iron bar is fixed (*Picture* 95), the expansion of the iron downwards is counterbalanced by that of the brass in the upward direction The effect is that the distance between the ends of such a compound bar remains constant



Picture 95

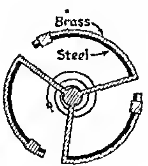
We can see therefore that a pendulum could be composed of iron and brass bars in this way, and that its

effective length would be the same for all temperatures Pendulums for clocks are often constructed of different materials, so that the expansion of one metal in one direction is compensated by the expansion of the other metal in the opposite direction These pendulums are known in the clock-making trade as gridirons, because the two metals are arranged in a gridiron pattern (*Picture* 96) Such a pendulum keeps accurate time with its swings, no matter how much the temperature varies, and no adjusting screws are required because the length remains constant



Picture 96

In ordinary watches a heavy rimmed *wheel, known as a balance-wheel, swings* to and fro to regulate the speed of the works, just as the pendulum does in a clock When the day is hot this balance-wheel expands, takes a longer time to describe its swings, and so causes the watch to lose time In expensive watches, however, and in chronometers used on ships, the balance wheels are always *compensated* (*Picture* 97) The rim is made in segments, and each part consists of two metals, generally steel and brass—the brass forming an outer rim to the steel When the day is warm the metals



Picture 97

expand, and the expansion of the brass being greater than that of the steel, the segments curl inwards But the spokes of the wheel are firmly fixed in the hub and they expand outwards Because the free ends of the segments are loaded these two influences counteract each other, so that the rate of the swing of the wheel is unaltered

One of the greatest handicaps to the use of steel frames for windows in houses and factories is the different rates of expansion of steel and glass This makes it necessary to have the frame a little larger than the glass plate which it is to accommodate If platinum were a cheap metal this difficulty would not arise, for a platinum frame would expand at the same rate as the glass Why is it impossible to seal a copper wire into a glass tube, although a platinum wire is easily sealed into it? It is because the copper contracts more rapidly than the fused glass, and so a crack occurs and prevents a tight joint being made. The platinum, however, contracts at the same rate as the glass, and together they make a perfect joint When we wish to stretch an iron bar, even to a minute extent, we find it necessary to use a great force So also when we expand an iron bar by heating, a great force is exerted That is why, when constructing a furnace, the metal bars which form the hearth are not fixed in the masonry, for when heated the force of their expansion would break down the stone-work We can make a novelty which depends on this principle by taking an old

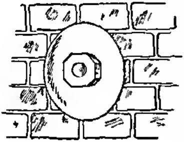
photographic film, and cutting it down to the outline of a fish When it is placed on the open palm (*Picture* 98) the force of expansion, due to the heat received from the hand, causes the "fish" to curl up, turn on its side, and roll about

Picture 98

Just as it is so difficult to stretch an iron bar it is equally difficult to compress it, and this accounts for the great force developed during contraction A wheelwright makes use of this force when fitting a metal rim to a wheel First, the iron hoop is made less in diameter than the wheel for which it is intended Next, it is so expanded by heating that it slips over the wooden framework Afterwards the wheelwright rapidly cools the iron by some such device as lowering the whole wheel into a tank of cold water The iron then shrinks and grips the wood work firmly, and at the same time drives home all the joints in the framework

Another application of this principle is the method used by property repairers to draw together the gable ends of a house which is in a state of collapse To do this a long iron bar having a screw thread at each end is passed through the house and projects through each gable-end Plates fit on the bar and are screwed to the walls by means of nuts (*Picture* 99) The bar is generally made hot by wrapping it round with oil-soaked rags which are then fired Whilst hot and expanded the nuts are

tightened, and then the bar is quickly cooled by pouring water over it The force of contraction draws the plates together, and at the same time the walls are drawn towards each other also



Picture 99

The boilermaker uses his rivets whilst they are red-hot and expanded, making them grip the plates he is fastening as tightly as possible When the rivets cool they contract, and the plates are more securely clamped than is possible when human force only is applied

Further Experiments.

1 Place a brass rod projecting over the edge of a table so that it just balances Now heat the projecting portion Explain what you observe

2 Stretch a metal wire between two vices Attach a paper pointer to its mid point Now, without burning the pointer, heat the wire and explain what you observe

3 Repeat Experiment 2, using a piece of india rubber Is the result the same?

4 Loosen a glass stopper from the neck of a bottle in which it fits tightly Use a method which is not dangerous

5 Arrange a metal poker so that one end is fixed firmly in a block of wood and the free end rests on a round cork, which is itself resting on its side on a wooden box Attach a paper pointer to the cork and heat the poker over a gas jet Explain the motion of the pointer (*a*) whilst the heating takes place, (*b*) as the poker cools

14. How Temperature May Be Measured.

We have all seen the small celluloid ball which is used for table tennis. It is very light and easily crushed out of shape. Is it possible to restore a ball when damaged in this way? Let us see. Hold it in front of a fire and warm it gently—*for celluloid is very inflammable*. If this is done with care there is no danger to be feared, and in a moment or two the ball regains its spherical form. Useful as this hint is, we may discover a greater interest in the reason for its effectiveness. We have already noted many instances of how a gas occupies the whole of the space within its container. This we have attributed to the absence of cohesion between its molecules.

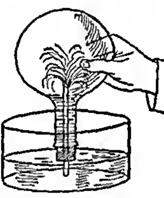
A famous scientist named Graham, has considered the behaviour of gas molecules when they are enclosed in a vessel, and has propounded a very probable theory of what happens. We can illustrate his theory in this way. Imagine each molecule of air in the crushed ball as a little imp shut up in a prison with millions of minute neighbours. Regard each of the imps as a gymnast who is *always* moving about at a tremendous rate, rubbing shoulders with his neighbours, and, after a zig-zag path, striking the wall of his pri
All day and all night there must be great
in that prison. A remarkable thing about
imps is that they never rest and yet they .

When an imp rushes against the prison wall he rebounds with exactly the same velocity as he struck it Imagine what it will be like now that the walls of the prison are pushed in The poor imps must now do their gymnastics in less space than they have been accustomed to Although they beat against the prison wall they cannot push it back Truly this is a serious state of affairs! There is one way in which we can help the poor imps to regain the space they have lost. Like a good many ordinary folk, the imps work harder and jump faster when they are warm Warm imps will jump against their prison wall more frequently in a definite time and with a much greater velocity than they will when they are cold In order to supply the imps with warmth we must heat the prison wall from the outside, and it is found that the heat passes to the inside On receiving the warmth their gymnastics become more vigorous, and by striking the wall oftener and harder they push it back to its former position This is something like what happens to the molecules of the air inside the celluloid ball The heating has caused the air to occupy a greater space, and hence the ball becomes round once more What is true of air is true of all gases—they expand when heated

At the pantomime it is a favourite joke of the clown to place a small sausage shaped balloon in a frying-pan, and warm it over a candle The heat of the candle flame passes through the metal of the pan and through the skin of the balloon, and thus reaches

the air inside The air expands, and the balloon swells and swells till it strains the skin so much that the balloon bursts with a loud report

When once a gas has been expanded by heating, does it continue in its expanded state? The clown's balloon gives us no answer to this question We can, however, test this by a simple apparatus Take a thin glass flask—the kind used for holding olive oil will answer the purpose very well (*Picture* 100) Select a cork which fits tightly in the neck of the flask, and having bored it, carefully pass through it a glass tube drawn out to a fine jet at one end The tube must be so arranged that when the stopper is in the neck the jet is well within the flask If any difficulty is experienced in obtaining a glass tube, a suitable substitute can be made by using a long, hollow goose quill Now warm the flask *only* in front of the fire until it is so hot that it must be held in a cloth Consider what has happened Much of the air in the flask has been expelled by heating, and the air remaining in it is hot and expanded Now insert the cork and tube, and then invert the whole so that the open end of the tube dips into a basin of water (*An ordinary* household basin will do Coloured water is more



Picture 100

spectacular.) From this moment onwards the air begins to cool. Does it contract as it cools? What do we expect to take place? There will be a smaller pressure inside the flask than outside. No air can enter the flask because the entrance tube is below the water surface. From what we know of air pressure, we shall expect the water to be forced up the tube and into the flask until the air in it is at the same pressure as the outside air. As we watch we see that this is actually taking place, and a very pretty fountain is playing within the flask. In a short time this fountain ceases. Does the water fill the whole flask? No, there is a layer of air above it. There is only a small quantity, it is true, and yet not long ago this same air was hot, and occupying the whole vessel. From this we can safely assert that, while the pressure remains constant, a gas contracts when it cools.

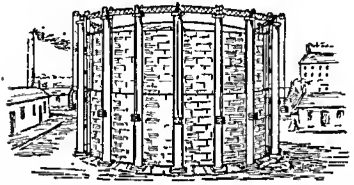
Like most natural phenomena, the behaviour of gases on heating is sometimes convenient for us in our everyday life—and sometimes otherwise. The cyclist does not need to inflate his tyres so much in hot weather as in winter, because he can allow for the effect of the sun's rays heating the air within. For the same reason a football is liable to be flabby when in use, if it has been inflated tightly in a very hot room. It is the expansion of the gas with which soda-water is charged that causes siphons of this beverage to burst during hot weather. Makers of the gas called oxygen store it in the strongest steel

cylinders, but, as a precaution against expansion, they advise purchasers to store the cylinders in a cool place

One of the economies effected by the army authorities during the Great War depended upon the expansion of a gas when heated The gas, chlorine, which was widely used in gas attacks, was sent out to France stored in large metal cylinders. When these were returned it was often found that they still contained a small quantity of chlorine. Some one suggested that this wastage could be avoided if the cylinders were kept warm when in use, for then almost the whole of the gas would leave the cylinders This was tried, and the efficiency of the British gas attacks was greatly increased in consequence Unfortunately, many casualties were caused in our own ranks by the force of the expansion of this gas. Several cases occurred where the heat from the breech of a gun, which was used to fire gas filled bombs, was sufficient to expand the gas in the bombs so much that a disastrous explosion was caused Occasionally we read in the newspapers of similar tragedies when unthinking housewives have attempted to heat stoppered bed warmers in a hot oven

The degree of expansion of a gas when heated was first discovered by a French chemist called M Charles This experimenter found that, for the same rise of temperature, all gases expand equally His apparatus was very intricate and expensive, but we can arrive at a similar result by using our powers of observation

The gas-holders of large gas-works often remain charged for days together without any gas being either withdrawn or added (*Picture* 101). On examination from the outside it will be found that

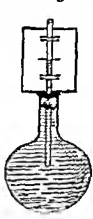


Picture 101.

these gas-holders are usually provided with a vertical scale marked on them in feet and quarter-feet. Let us visit one on a certain day when the weather is cool, and we may find the 27-feet mark just visible above the water-tank in which the gas-holder floats. Also observe on a centigrade thermometer the temperature in the street for that day. We must now wait until the weather is such that the thermometer records a temperature two degrees higher than before Again let us visit the gas-works, and we find that the gas-holder has risen to the point where the mark showing 27 ft 3 ins is almost visible This rise is due to the expansion of the gas within the gas-holder, and the expansion is itself due to the increased warmth of the atmosphere. From these

figures we may calculate the fractional increase of the gas for one degree increase in temperature Our result is almost identical with that of M Charles, viz, $\frac{1}{273}$ of the volume of the gas at 0° C for every 1° C rise in temperature

We have seen that, when heated, solids expand a little and gases very much Let us now consider what is the effect of heating liquids To investigate this we may use the flask and tube which we prepared for the experiment to show how gases contract when cooled (*Picture* 100) First of all, fill this flask with coloured water Then, by pressing in the stopper and tube we shall cause the liquid to rise in the tube A strip of paper may be easily fixed, as shown (*Picture* 102), and on it we may record the height of the liquid Place the flask in a pan of hot water Heat begins at once to pass through the glass to the liquid inside Note what happens to the level of the liquid It falls, because the heat causes the flask to expand first, and the liquid must accommodate itself to the increased capacity of the flask After this stage the liquid in the tube rises, because the water expands to a greater extent and more rapidly than the flask Again note the height of the liquid in the tube Now cool the flask and its contents in a basin of cold water What happens? The liquid runs down the tube and is



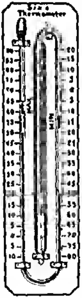
Picture 102

obviously contracted If the flask is cooled in air it is seen that the level of the liquid gradually returns to the place it occupied at first How do we explain these results? Could we use our instrument to decide which was the hotter of two baths of water? Answers to these questions readily suggest themselves

All liquids do not expand equally We can demonstrate this by constructing a second instrument exactly like the one we have just used, but this time using methylated spirit or turpentine instead of water When the two flasks are placed in the same hot bath we soon see the difference in the heights reached by the two liquids The spirit rises more than the water What does this indicate?

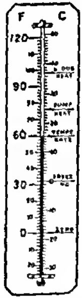
It may be thought that the flask and tube instrument would be a convenient arrangement for comparing the degree of hotness of two water baths In practice, however, there are one or two serious objections to this instrument One is that it takes a considerable time to warm all the water within the flask, and during that time the bath outside the flask is cooling This objection can be overcome by using a small bulb on the end of the tube instead of a flask By using thin glass we gain the additional advantage that the heat passes quickly to the liquid in the bulb We have still to overcome the difficulty that, owing to the width of the tube, the rise of the liquid is not very marked If we use a tube of very narrow bore this objection is avoided, and slight expansions are recorded by a rise of liquid which is

quite noticeable. When mercury or alcohol is substituted for the water in the bulb the variations are still more pronounced. There is another improvement we can make in our instrument, and that is by withdrawing the air from the tube and sealing up the end. If we do this we further reduce resistance to the rise of the expanded liquid. Finally, a scale *etched on the glass, or fixed behind the tube,* makes it easy for us to read the amount of expansion which takes place.



Picture 103.

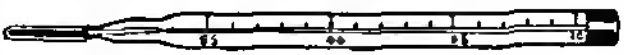
Picture 104.



Picture 105.

Such an instrument is known as a Thermometer (*Pictures* 103, 104, 105), and is very useful in estimating the degree of hotness of a substance in which its bulb is immersed. *It is found* convenient

to fix the scale by dividing the length of the tube into equal parts To do this, "fixed points,' as they are called, must be determined The fixed points are (1) the height at which the liquid stands in the tube when the bulb is surrounded by melting


A clinical thermometer

Picture 106

ice—this point is known as the **freezing point**, and (2) the height at which the liquid stands when the bulb is surrounded by steam—this point is known as the **boiling point** Under either of the conditions we have named the liquid will remain quite steady Having marked these points the distance between them is subdivided If the divisions are $\frac{1}{100}$ of the total distance, the scale is said to be a centigrade scale, and the lower fixed point is the zero mark on the scale This is the scale used by scientists the world over, and by ordinary people in lands which have adopted the Metric System If the distance between the fixed points is divided into 180 equal divisions, and the lower fixed point labelled 32°, the scale is a Fahrenheit scale This scale is adopted for general purposes in the British Isles

Many adaptations of the thermometer are in use, but all of them depend on the same principle In our homes we sometimes see alcohol thermometers mounted in wooden holders, but in chemical works chemists use delicate mercury thermometers for their

experiments The student of geography uses a specially constructed thermometer to record the maximum and minimum temperatures of the outside air (*Picture 103*), the baker has an oven thermometer, the poultry farmer an incubator thermometer, and the doctor, when he wishes to tell the temperature of our blood, uses a clinical thermometer (*Picture 106*) In the clinical thermometer the tube is so made that when once the mercury has expanded and left the bulb it cannot return, even when cooled, unless a sharp jerk is given to the instrument

Further Experiments.

1 Fit up an apparatus which can be used to find which is the hotter of two baths of water Now use your apparatus for this purpose

2 Press corks lightly into the ends of an iron pipe. Place the pipe over a lighted gas-jet. Explain what you discover

3 Slightly inflate a toy balloon and then hang it in the warm sunshine What explanation will account for the observations you are able to make?

4 Fill a bottle, having a well fitting stopper which is bored with a fine hole, with coloured water so that the bottle and the hole in its neck are full of coloured liquid Place the body of the bottle in a vessel of hot water for a few minutes, and then withdraw it and allow it to cool Notice the amount of liquid remaining in the bottle How may the difference be explained?

5 Fill a small bladder with water and hang it in a pan of boiling water Explain what happens to the bladder

15. Why Clothes Keep Us Warm.

When we leave a poker with one end in the fire for some time, we know that before long the other end becomes so hot that we hesitate to grip it with the hand The heat of the fire has passed from one end of the metal to the other Why is this?

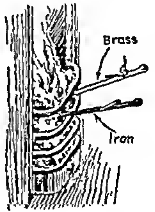
To answer this question we must refer to what we have learned about the way matter is constituted Let us imagine that the molecules of which the metal is composed can be magnified so as to be seen with the eye Each molecule appears like a marble resting against other marbles Now imagine a row of marbles, all hung in a line from separate strings, so that each marble touches the next one We know that if we set the end marble swinging it will strike its nearest neighbour and bounce away again at the same time causing the second marble to swing The swinging motion is passed from the second to the third marble, and so on down the line, to the marble at the opposite end, which is soon swinging to and fro This is exactly what has been taking place with the molecules of the poker The heat of the fire at one end has caused the molecules in that neighbourhood to begin to swing vigorously, and this vibration has been taken up throughout the whole length, and so has passed from one end to the other

The vibration of the molecules at any part of the poker causes that part of the metal to become hot,

the degree of hotness depending upon the rate of the swing of the molecules There are, of course, no actual strings from which the molecules are suspended, but the movement takes place as though there were. We notice in the experiment with the line of marbles, that although the vibration passes from one end of the line to the other, each separate marble is only very slightly displaced by the process In the same way each molecule in the poker does not move over a distance greater than an extremely small fraction of a millimetre, although the heat is transferred many thousand times this distance.

Transference of heat in solids by this method is known as **conduction**, and the substance through which the heat passes is known as a **conductor** of heat

Let us put two similar pokers, say one of brass and one of iron, into the fire so that their ends project equal distances outwards (*Picture* 107) Now balance the head of a match on the end of each of them We find that in a short time sufficient heat is conducted along the pokers to fire the match-heads The one resting on the brass takes fire before that on the iron, showing that heat has passed through the brass more rapidly than through the iron



Picture 107

Similarly, if we put two spoons, one made of silver and one of bone, into a cup of hot tea, we find that the heat passes more quickly through the silver spoon than through the bone one Because of this difference in power of conduction or conductivity we say that silver is a better conductor than bone, and brass a better conductor than iron

Some materials are very poor conductors So poor a conductor is wood, for example, that a burning match can be held in the hand without inconvenience until the flame is only a very short distance from the finger tips This shows clearly that hardly any heat is conducted along the splint Glass also is a poor conductor, for a glass blower, having made one end of a three inch tube red hot, can place the opposite end between his lips so as to blow a bulb on the tube Straw is another material of low conductivity, hence its use as bedding for cattle, and, when woven together, as mats for dishes We find it more comfortable to step from a warm bath on to a cork bath mat than on to a piece of linoleum Why? The cork does not readily conduct heat from the soles of the feet, and so cause them to feel cold as the linoleum does Engineers surround steam pipes and engine cylinders with "non conducting" packing to prevent loss of heat

twenty four pennies, so as to make a metal cylinder surrounded by paper, and make a similar package, by wrapping a short length of wooden blind roller in paper Hold each in turn over a gas jet. The second cylinder is very soon scorched, but the package of coins is not scorched for some time This is because the heat is carried away from the paper more rapidly by the metal of the coins than it is by the wood

Pick up a garden spade on a cold day It feels very cold when we grasp the metal part, but less cold if we grip the wooden handle This is because the heat of the hand is more rapidly conducted away by the metal than by the wood The difference of conductivity explains why the body of a metal teapot becomes unbearably hot to the hand, although the ebony handle is scarcely warm In some metal teapots the handle is made of metal also, and yet it does not get warm, for it is joined to the hot vessel by two studs, made of substances such as bone or ebony, which have low conductivities A smoker's pipe can be held between the teeth in comfort, for, although the burning tobacco may make the bowl of the pipe very hot, the vulcanite of the stem is such a feeble conductor that little or no heat passes along it

The conduction of heat plays an important part in our lives Our dishes, pans, kettles, and other cooking utensils must be made from good conducting material, so that their contents may be easily warmed For the same reason the bottom of an oven is made of iron, but, to prevent heat escaping after the oven

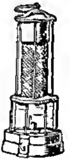
has been made hot, its sides and top are often lined with firebrick or asbestos, both of which are poor conductors.

Asbestos is such a poor conducting substance that it has been widely used as a building material, after it has been pressed into sheets which can be nailed on a wooden frame-work. An asbestos building is found to be very cool in summer, for the sun's heat is not conducted to the interior; but, in winter, the warmth is kept inside, because the walls do not conduct the heat away to the outer air.

One of the most romantic stories in the history of science is that of the invention of the Miner's Safety Lamp. This is due to Sir Humphrey Davy, a scientist, who was convinced that much of the danger in coal-mines could be avoided if miners were provided with lamps which could not cause an explosion. In a coal-mine there is constant danger of explosion, owing to the presence of fire-damp, a poisonous gas which oozes from the coal-seams and forms with the air a highly explosive mixture. Up to the time of Davy many lives had been lost in the pits, because the naked lights carried by the miners caused sudden explosions. In many pits fire-damp accumulated to such an extent that the workings had to be closed. Many unsuccessful efforts had been made to overcome the difficulty before Davy took up the problem. After months of patient experimenting he felt sure at last that he was on the track which would lead to a solution. He had discovered that when wire is woven

into gauze it does not allow a flame to pass through it, even though the atmosphere on the other side of the gauze may be inflammable This is because the wire of the gauze conducts the heat of the flame away so rapidly that the gas on the opposite side of the gauze does not get hot enough to ignite Davy, therefore, made a lamp chimney in the form of a gauze cylinder, having one end closed with a brass plate (*Picture* 108) He attached this chimney to an ordinary miner's lamp, and by this simple means made it proof against explosion

Many mine-owners to whom Davy showed his invention were sceptical about it, so a trial was arranged A story is told that a mine was selected which had been closed because of the presence of fire-damp. First of all a cage containing a live mouse was lowered down the shaft and kept there for a few minutes When the cage was drawn up to the surface again the mouse lay dead at the bottom of the cage It was quite clear that the mouse had been poisoned by the fire damp in the mine



Picture 108.

One of Davy's lamps was now lighted and lowered into the explosive gas to the same depth as the cage had been Everyone waited anxiously, many expecting to hear the report of a loud explosion, but everything remained still and quiet The lamp was withdrawn and found to be burning as brightly as ever It had remained burning even when fire damp

was present and yet no explosion had taken place. Thus had man achieved one more triumph After this, thousands of similar lamps were made, and an Act of Parliament was passed forbidding the use of a naked light in mines where the air was known to be fiery because of the presence of fire damp To day the miners still use Davy lamps which have been improved by adding a clear glass window to the gauze chimney Another great advantage of the Davy lamp is that the miner can judge by the flame of his lamp whether he is in a danger zone, for when there is much fire damp present in the air, it passes into the flame and burns round it in the form of a long blue cone When the miner notices this he is made aware of the presence of the poisonous gas and quickly withdraws to a place of safety

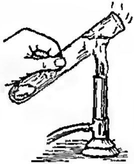
Heat may be conveyed also through liquids by conduction but, with the exception of mercury, most liquids are poor conductors We can illustrate the low conductivity of methylated spirit by pouring it over a few raisins in the bottom of a shallow bowl and then igniting the liquid by throwing a burning match into it (*Picture* 109) Whilst the flames are leaping up, we can withdraw a raisin from the bottom of the bowl by means of a fork The raisin can be put in the mouth and eaten at once, for it is quite cold The heat of the spirit

Picture 109

burning on the surface has not been conducted through the liquid to the raisins.

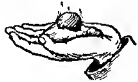
The following experiment should only be attempted by experts: Hold a *few drops* of spirit in the palm of the hand, and light it with a burning match It produces the illusion of holding fire in the palm of the hand. In this experiment the palm is quite cool, because the heat of the flames does not pass by conductivity through the liquid layer.

Water has a very low degree of conductivity, and it is possible to weight a piece of ice so that it falls to the bottom of a vessel, and remains there unmelted, whilst the surface water is made to boil by heating with a gas or candle flame (*Picture* 110)



Picture 110

Of all gases air is almost the poorest conductor. We can show this by holding a heap of coarse powder like plaster of Paris or sand in the palm of the hand, and placing on the heap a small iron ball which has been heated in the fire (*Picture* 111) Provided the ball is not too heavy, it rests on the powder without scorching the hand If the powder is compressed to a cake by the weight of the ball, the hand soon becomes unbearably hot. Whilst the plaster remains as a coarse powder the heat of the ball does not pass



Picture 111

easily through the small air pockets, but when the air-pockets are removed by compression, the hard solid conducts the heat quickly to the hand

The cavity which is generally left between the inner and outer sections of the walls of our houses serves as a bad conductor round them, and so helps to keep our rooms cool in hot weather and warm in cold weather This principle is also applied in constructing meat safes and refrigerators, which are built with double walls having an air space between Often cork dust or sawdust is placed in the cavity to increase the number of air pockets, which prevent heat escaping or entering In very cold countries like Canada loss of heat by conduction of the wall materials is made as low as possible by the air-pocket method, and even the windows are made double with an air space between them

In places where fuel is scarce and expensive, cooking is often carried out by using a hay-box The joint or the stew is first heated in the ordinary way until it is almost cooked Then the cooking vessel is removed and placed in a box where it is surrounded by hay The lid is securely fastened down, and the air pockets made by the hay retain the heat, so that the cooking proceeds until the food is ready to be served

We do not usually think of snow as a warm substance, but it forms enough air pockets as it lies on the ground in winter to prevent the warmth of the earth escaping to the cold atmosphere In this way

it serves as a blanket, protecting the tender roots and seeds which lie just below the earth's surface The Esquimaux find their huts, built from slabs of compressed snow, quite comfortable during the Arctic winter Many cases are known where sheep have been dug out from deep snow drifts, in which they have been buried for days and have been found little the worse for their experience

The wrapping of the spout of a pump with straw in winter is effective because of the poor conductivity of the air which is enclosed among the fibres of the straw In hot weather ice is covered with sackcloth to prevent the heat of the outer air passing to the ice and causing it to melt

In our choice of clothes and bedding material we depend very much on the poor conductivity of air. Eiderdowns and blankets keep us warm in bed because the materials of which they are made enclose air which does not allow the heat of our bodies to be carried away Our winter clothes are chosen for exactly the same reason The poor conducting power of air also explains why light cellular fabrics are often quite as warm as heavier clothing A pair of loose-fitting gloves feels warmer than closely fitting ones because the layer of enclosed air prevents the heat of the hands from being conducted away We can now understand how nature has provided many birds and animals with protection against severe weather The sheep has its fleece, the bear has its thick fur, the duck, the hen and other birds have

their downy feathers—all these creatures are protected by the air pockets caused by their covering

Further Experiments.

1 Wrap a lump of ice and a hot fire brick in separate pieces of blanket for half an hour Remove the wrappers and state what you observe What is the function of the blanket in each case?

2 Coat the handles of spoons of silver, plated nickel, and bone with a thin layer of wax Place all three spoons in the same vessel of hot water, but keep the handles out of the water On which spoon does the wax melt first? How do you account for this?

3 Place a pint of water in each of three equally sized pans—one of iron, one of copper, and one of aluminium Heat them one after another over the same gas jet Notice the times taken to boil the water in each Explain the result

4 Attach a marble to the lowest point of a test tube by means of wax. Place mercury in the tube Insert a red hot wire, and notice what happens to the marble Explain this

5 Turn on a gas jet and hold a wire gauze above it. Light the gas above the gauze What happens to the gas below the gauze? Will it ever ignite? If the gas below the gauze is first ignited what happens? Is there gas above the gauze now? Can it be ignited?

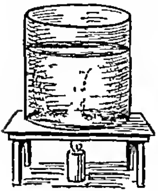
16. How the Bath Water Becomes Hot.

The modern steam engine, invented by James Watt, produced a revolution in the industrial world It is said that, as a boy, Watt discovered the power of steam when watching the behaviour of a kettle lid as water boiled in the kettle

From the simplest sources wonderful discoveries often spring Let us consider an operation similar to that which gave Watt his idea of steam-power, and try to discover for ourselves some of the wonders it reveals We have often seen coffee brewed at home A pan of cold water is set on the fire and when the water is warmed, a quantity of ground coffee is sprinkled into it Now look carefully and it will be seen that most of the grains are floating on the surface of the water, and remain there until the liquid is very hot At this stage they are drawn down into the liquid, but reappear after a short time This process continues until the liquid boils Then we see the coffee grains swirling about rapidly by the commotion set up as the water changes into steam

What reason can we find for this behaviour? A simple experiment will make it clearer Take a thin glass vessel, the thinner the better, and on the bottom of it sprinkle a little red chalk dust Cover this with a layer of water three or four inches deep Now place the

vessel over a gas jet, or candle, and arrange an asbestos 'boiling mat between a small flame and the vessel (*Picture* 112) Gradually the water gets warmer and we notice that the chalk grains, just above the heated spot, begin to rise to the top Here they spread out, and then fall gradually down the colder sides of the vessel, thus returning to the heated region



Picture 112.

As the heating continues we find that the chalk-dust moves more and more rapidly

We know that the chalk cannot move of its own accord, but it is so light that any movement of the water will carry it along We conclude, therefore, that the path of the solid particles is the direction of the movement of the water If we are fortunate enough to have a beam of sunlight passing through a glass vessel in which water is being heated, we can see by the shadows that the water is moving just as the chalk dust indicated in our previous experiment

We have still to enquire why heating should cause a liquid to move It is important to observe first of all that the water rises from the heated region Now, we have already noted that most substances expand when heated, and this is true of the lower layers of water in the glass vessel The heated water becomes lighter bulk for bulk than the water above

it, and consequently rises in the vessel Other water must flow into the heated region to take the place of the water which has moved upwards. As this process continues the whole of the liquid soon begins to move round and round

Whilst each particle of water is rising from the heated area, it is continually giving out some of its heat to warm other parts of the liquid The coolest part of the liquid is therefore at its surface, which only becomes warm by the motion of the warm particles from the bottom of the vessel

This wonderful process is known as **convection** (Latin *con*, along with, *vectus*, carried), because the actual particles of the substance move and are carried away Such a method of carrying heat cannot take place in solids, for the particles of solids are not of themselves free to move very far on account of cohesion, but must return to their former positions after any vibration due to heating In liquids and gases, however, convection currents are easily set up, but in solids heat is transferred by conduction, as was explained in Chapter 15

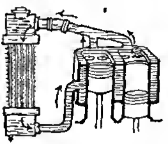
Convection in liquids serves a double purpose in helping man The currents may be employed in carrying heat to a cold place, and also in conveying heat away from a hot place

A novelty which we can devise for ourselves will help to make this clearer Fold a piece of stout drawing paper so as to form a rectangular box, and stitch the sides to make them secure Make a holder

for this box by bending one end of a long piece of iron wire, and then coil the free end round a candle (*Picture* 113) The box thus rests above the wick. Now fix the candle in a candlestick, fill the box with water, and light the candle We might expect the paper of the box to be scorched, but a careful examination will show that it is not damaged at all by the flame In a minute or two the water in the box is boiling quite merrily The water inside the box carries away the heat of the candle flame by convection, so that the paper is not even singed the heat is used up in boiling the water

Picture 113

This is the principle of the cooling jacket of water which surrounds the cylinders of a motor car (*Picture* 114) Whilst the engine of the car is running the cylinders become very hot, and the water in the jacket is heated This heated water moves away, and its place is taken up by cooler water After this is heated it also moves away to the cooler region of the radiator In succession these heated portions move away, become cool and return again to help in cooling the cylinder

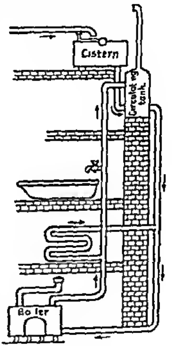


Picture 114

One of the best methods of heating the rooms of a large building is to have in the basement a furnace

which heats the water contained in a boiler The water becomes very hot and rises by convection to the upper stories, passing through coils of pipes, which help to distribute its heat Where this system is used the first floor rooms always get warm before the upper rooms Why is this?

By the time the hot water has travelled to the place farthest away from the furnace it has become much cooler and heavier, and it gradually sinks back to the boiler to be again heated In a central heating system, two pipes are always connected with the boiler One is generally so hot that it is uncomfortable to touch with the naked hand, whilst the other is cool One of these pipes is joined on to the upper part of the boiler, and the other is connected with the lower part How can we account for this arrangement? Which of the pipes do we expect to be the hotter?



Picture 115.

In houses where hot water is required for baths and lavatories the boiler is generally situated behind the kitchen fire, and heated water passes upwards to a large copper tank in one of the higher rooms (*Picture* 115)

There is also a cistern in a still higher part of the house, and from this, cold water is supplied to the tank When the kitchen fire is burning convection currents are set up very quickly and warm all the water in the circulating tank When some of this warm water is drawn off, say at the bath room tap, cold water flows into the tank from the cistern, so that there is always a good circulation of water If we listen carefully near the tank we can often hear the murmur of the circulating water

It is interesting to study the way the plumber has arranged the pipes leading to and from the circulating tank, and from their positions to decide the function of each pipe

A boiler which has been in use for some time may become choked with a hard, scaly substance, which should be removed How is this to be done? To take out the boiler and renew it would be an expensive undertaking, but, unless this is done, the only way to the interior is by the feed pipes Under these circumstances a wise householder dissolves a pound or so of alum in the water of the cistern at the top of the house By running out water at the hot water tap, the alum solution flows down into the circulating tank Every tap is now closed, and for an hour or two the kitchen fire is well stoked The alum solution circulates round and round and, when in the boiler, it dissolves the scale When the hot-water taps are again opened, the liquid which runs to waste carries with it the objectionable scale in

solution The path taken in the pipes by the alum solution is the direction of the flow of the convection currents

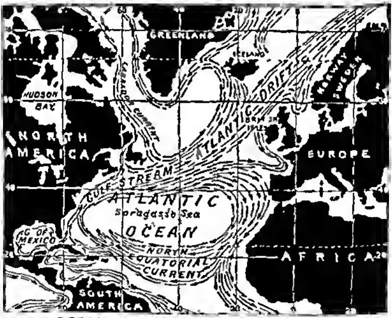
Wonderful as is this method of warming buildings it cannot compare with the wonder of the warming of a continent All the year round the water of the ocean is moving If it remained stagnant many marine plants and fishes would die, and some parts of the sea would become much more salty than others, but more than this, the climate of many countries would be bitterly cold The chief reason why this does not occur is because the surface water of the ocean behaves, on a large scale, like the water circulating through the hot water pipes of a house

The seas near the Equator are subjected to the great warming influence of the sun's powerful rays Near the polar regions the seas are always icy cold The result is that convection currents are set up between these two regions The surface water of the ocean does not move directly North and South, from Pole to Equator and back again, because the spinning round of the earth, the direction of prevailing winds, and the shape of the land masses jutting into the sea all modify the direction of the currents

A map (*Picture* 116) of the ocean currents in the Atlantic will illustrate what actually happens The water in the Gulf of Mexico—which is part of a great system of surface circulation—is heated by the sun's rays, and moves in a north easterly direction in a swift current known as the Gulf Stream. As it

moves more and more northwards it loses much of its heat, but when it reaches Europe it is still moderately warm The Atlantic Drift, as the current is now known, washes the coast line of Great Britain and tempers what would otherwise be a cold climate. It is because of this action that the Gulf of Mexico has been popularly called the "Boiler-house of Great Britain"

Since water is constantly moving away from the



OCEAN CURRENTS IN THE ATLANTIC
Picture 116

tropical seas, cold water must flow towards them from the polar regions This compensation is supplied, in the case of the West Atlantic, by a stream of water known as the Labrador Current. This current passes

Labrador travels southward as far as Cape Hatteras on the North American coast, probably cuts horizontally through the stream from the Gulf of Mexico and is, as a consequence, heated and sent on its way across the Atlantic.

The warm currents of the ocean often exercise an important influence on the commerce of a country The amount of trading possible is decreased when ports are ice bound for a portion of the year Hammerfest, in Norway, in spite of its nearness to the North Pole, is an open port all the year round, because the warm Atlantic current washes its shores. On the other hand, the entrance to the Baltic Sea, which is farther away from the North Pole than Hammerfest, is blocked with ice for three months of the year as it receives no warm ocean currents Again the warm Atlantic Drift accounts for the open ports of England, whilst the Canadian ports on the River St Lawrence, even though in a lower latitude, are closed for some months of the year because the warm currents of the ocean do not reach them

Further Experiments

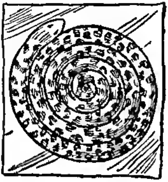
1 Try to boil a pan of water by heating it from above Do you succeed? If not, why not?

2 Place an empty egg shell among the hot cinders of a fire Notice how quickly it scorches Fill another shell with water and place it in a similar position Is it scorched as quickly as the empty shell? How is this explained?

3 Float a piece of ice in a pan of water Place the pan over a fire How and why does the ice melt?

17. Why a Room May Be Draughty.

On a sheet of stiff paper draw a spiral, varying the pattern so that the outer end of it represents the head of a snake (*Picture* 117) Decorate the paper by painting it to represent a snake's skin and then cut along the line drawn Now hold up the paper by a loop of thread passed through the centre (*Picture* 118) It will have the appearance of a coiled snake hanging downwards by



Picture 117

the tail Hang the "snake" a short distance above a lighted candle, but be careful that it does not catch fire Notice that the snake twists round and round with a peculiar writhing motion Extinguish the candle, the writhing and turning become less vigorous, and in a few moments cease altogether When the candle is relighted the snake's motion begins again Can we explain why this happens?

Picture 118

We may conclude that the motion of the paper is produced in some way by the candle flame This is quite true, and if we hold one hand just above the lighted candle we can feel the heat for ourselves Of course, it is not very

intense It feels as though a stream of warm air were flowing towards the hand from the region of the flame This upward movement of warm air was the cause of the paper turning round and round

Let us collect illustrations of the fact that heated air rises One of the simplest is the behaviour of small particles of soot in a chimney Another is the quivering appearance of objects when looked at across a hot coke fire or a lime-kiln This apparent quivering is due to the hot air which rises from the fire and causes the unequal bending of the rays of light passing from the objects to our eyes In shop windows we often see attractive advertisements which illustrate the effect of heated air when rising A piece of transparent tracing paper, with the advertisement printed on it, is attached to a small disc of cardboard to form a shape like a tumbler (*Picture* 119) This disc is cut in such a way that parts of it can be turned upwards to act as a propeller

Picture 119

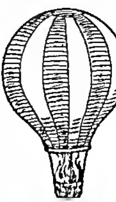
The whole is now placed over an upright electric lamp so as to balance on the topmost point of the bulb When the light is switched on the lamp serves two purposes (1) it illuminates the advertisement, and (2) when it is warm it causes the air around it to become warm and to rise In escaping through the top the heated air presses against the cardboard vanes, and the disc with its attached advertisement

to rotate The effect is very striking and attracts attention Another illustration of the same principle is seen in the cowls or smoke preventers fixed on the tops of chimneys These are made to rotate by the heated air which ascends the chimney from the fire

Let us now enquire what happens to the air after it has been made to rise by heating Of course we cannot see the air itself moving but we can judge the direction of the air current if we obtain a very light object to act as an indicator Release a small piece of thin paper, like a cigarette paper, above a hot oil stove The paper floats up into the air for a considerable distance and then begins to fall again Notice that the rate at which it falls is greater than the normal rate of fall of such a paper, in fact it appears to be drawn downwards This indicates that when the air is heated it circulates in the same way that water does The heated air rises and cooler air flows towards the heated region to take its place In the case of liquids we said this was due to convection, and we can use the same term to describe the circulation of the air

Let us enquire if an explanation similar to the one we deduced in the case of convection in liquids holds good for convection in gases Does the heated gas expand, become lighter, rise, then cool contract, and sink again? We have already shown that all gases expand when heated and a little thought will show us that they must become lighter Now the effect of this condition will be such that the heated gas

will rise This was proved many years ago by a French scientist, named Mongolfier, who wished to send a barometer up into the air to a great height At that time there were no aeroplanes and no envelope balloon was able to ascend the required distance Mongolfier therefore constructed a fire balloon, such as the Chinese had used centuries before (*Picture* 120) He prepared a pear shaped envelope of fire proof material having a wide opening at the bottom In a brazier just beneath this opening he kindled a fire, and the hot expanded air rose from it and distended the pear shaped bag It was necessary to weight the balloon to keep it down whilst the instruments were being attached When all the preparations were complete the ballast was removed and the balloon sailed upwards through the air for several miles The ascent continued so long as the air in the balloon was lighter than the surrounding air When, at last, the fire under the balloon died out and the air inside cooled and contracted the balloon could no longer rise but sank back to earth again



Picture 120

Mongolfier s experiment demonstrated the similarity of liquid and gaseous convection It has since been shown that currents are more easily set up in gases than in liquids Let us consider a familiar result of

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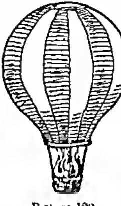


Picture 120

Mongolfier's experiment demonstrated the similarity of liquid and gaseous convection It has since been shown that currents are more easily set up in gases than in liquids Let us consider a

these currents Usually a dark discoloration can be seen on a white ceiling directly over an incandescent gas jet This dark patch is not soot, for tbe incandescent burner produces very little soot It is really a deposit of very fine dust particles which have been drawn from the surrounding air by convection currents set up by the heat of the gas flame We may say then that whenever air is heated it will try to rise, and, when possible, cooler air will flow in to take its place

The air cooled cylinder of a motor cycle is generally made with projecting flanges, so that the air in contact with the cylinder cannot rise directly upwards from the surface but is deflected to tbe side The flanges thus increase the number of convection currents which help to cool the hot cylinder

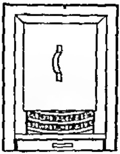
The tendency of cool air to move towards the hot region and thus cause a draught is a great aid in combustion processes, which depend for their support on a plentiful supply of air If we kindle a fire in an ordinary bucket the fire soon dies out because there is no indraught of fresh air to keep up the combustion When a few holes are made in the bottom of the bucket this difficulty is overcome and a draught is easily created We can illustrate the same principle by a simple experiment

Place a small lighted candle on a smooth table-top and surround it with a narrow lamp-glass Watch the flame of the candle, it gradually becomes dimmer and finally it is extinguisbed Why is this?

Now repeat the experiment, but this time rest the lamp-glass on two pennies so that there is a space at the bottom for the air to enter The candle now continues to burn for it is being steadily supplied with fresh air Instead of resting the lamp glass on the two pennies insert in the top of the chimney a piece of paper cut to the shape of a letter T (*Picture* 121) The candle again continues to burn because a circulation of air is established This circulation may be shown by holding a piece of smouldering paper over the lamp glass Note the path taken by the smoke When we examine any variety of stove, lamp, or fire we find that provision is always made for the indraught of fresh air

Picture 121

It is found by experience that it is more useful to lead the heated gas away from the hot region in such a way that the cool air does not come in direct contact with it This is why we place a blower in front of a fire (*Picture* 122), the incoming air must pass up through the burning fuel, and when heated it rises up the chimney The same reason accounts for the use of chimneys for oil lamps, furnaces, and house fires



Picture 122

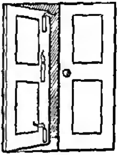
The Romans took advantage of convection in gases for warming their houses They arranged to have a furnace burning outside the house, and the hot gases

from this furnace passed under the floors of the rooms and thence to a chimney In the same way they often warmed the baths for which they were so famous Our most modern method of heating large buildings is very similar to this system Liverpool Cathedral is warmed on a modification of the Roman plan

Important as convection is to all forms of combustion, it is even more essential to enable us to obtain a supply of pure air The art of ventilation is the arrangement of convection currents One of the simplest methods of ventilating was used in the old coal-mines Two shafts were connected by a series of galleries or tunnels At the bottom of one shaft, known as the up cast shaft, a large fire burned continuously, and from it hot gas rose up the shaft and discharged itself into the surrounding atmosphere To supply the fire with air a draught flowed down the other—the down cast shaft—and along the channels formed by the tunnels In this way accumulations of foul air in the workings were prevented The method of ventilating a steamship is another application of the same method Fresh air is drawn down to the stoke hole of the vessel by means of large horn shaped funnels, which stand on the upper deck and lead to the interior of the ship In this way air circulates through the cabins and the holds of the vessel, and is discharged along with the smoke and the impurities from the boiler furnaces

In our climate our dwelling rooms are generally warmer than the outside air, because of the fires,

stoves, and lamps which we use indoors The warm, impure air in a room rises upwards towards the ceiling, as we may quickly discover by mounting a step ladder in a closed room where several gas lights are burning When a room is "stuffy,' open the door a little and hold a lighted candle in the opening (*Picture* 123) The greater the height of the door the better the results will be Notice the effect of the position of the candle on the direction of the flame At the top of the door the flame is wafted outwards, at the bottom it turns inwards, and about half way up it burns upright and steady This indicates the direction of the air currents, and shows us that a room may be best ventilated by an inlet for fresh air near the floor and an outlet for warm air just below the ceiling Many schemes have been adopted by builders to accomplish this The most common method is by placing perforated bricks in suitable places in the wall If we look around we can see many examples of this


Picture 123

(See *Further Experiments* page *168*)

Further Experiments.

1 In a saucer containing a layer of water stand a small lighted candle. Place a chimney round the candle. Explain what happens to the candle-flame.

2 Vary the conditions for Experiment 1 so that the candle continues to burn. Why is it now possible to keep the candle alight?

3 Burn a piece of camphor in a dish. Hold a clean post card about six inches above the flame for about a minute. Examine the card. Turn the card over and hold it thirty inches above the flame for the same time. The two sides of the card are not alike. Why is this?

4 Prop up the bottom sash of an ordinary house window by means of a board of the same width as the window. Hold a candle near the top sash. Explain the direction of the flame.

5 Burn a piece of tissue paper on a hot fire. What happens to the ash? Explain this.

6 Place a candle in a wooden box, and over the box put a lid which carries two chimneys, one of which is over the burning candle. Hold smouldering paper above the other chimney. Can you explain the direction in which the smoke travels?

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